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AIRCRAFT ARMOR - AN EMPIRICAL APPROACH TO THE EFFICIENT DESIGN OF ARMOR FOR AIRCRAFT

J. F. SULLIVAN

Reprint of WAL 710/506, 31 January 1944

Reissued January 1970

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172

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Monograph Series by

J. F. SULLIVAN

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FOREWORD

This "classical" study of aircraft armor was distributed as a Watertown Arsenal Laboratory report, WAL 710/506, to a specific list of recipients over 25 years ago and has been out of print for several years. Until recently it has also been under security restrictions. Accordingly, its contents are generally unknown to most of today's researchers in armor materials.

Although this study was written during a much less sophisticated era of materials technology and was limited to a review of materials reasonably available at that time whose relative performance was judged under the restrictive ground rule of retention of structural integrity under multiple projectile hits, it is believed that the report may contain information and philosophy "new" to today's researcher whose horizons fortunately are not limited by such restrictions.

J. F. SULLIVAN

31 January 1970

WATERTOWN ARSENAL

LABORATORY

EXPERIMENTAL REPORT

No. WAL 710/506

AIRCRAFT ARMOR

An Empirical Approach to the Efficient Design of Armor for Aircraft

By

J. F. Sullivan

Jr. Engineer

DATE 31 January 1944

WATERTOWN ARSENAL

WATERTOWN, MASS.

NAVY DEPARTMENT
BUREAU OF ORDNANCE
WASHINGTON 25, D. C.

(Re3) 2 June 1944

MEMORANDUM

From: The Chief of the Bureau of Ordnance
To : The Chief of Ordnance, War Department

Subj: Aircraft Armor, Efficient Design of.

Ref.: (a) Watertown Arsenal Laboratory Experimental Report No. WAL 710/506 Aircraft Armor
(b) NPG Report No. 21-43 - Ballistic Testing of Armor, Rev. A
(c) NPG Report No. 11-43

Encl.: (A) Three (3) copies of ref. (b)
(HW)

1. Page 7 of reference (a) under "Test Procedure" states: "Complete penetration according to the traditional Navy Limit criterion is attained when a projectile passes through the plate and remains intact. Since a ballistic limit is not reached until complete penetration occurs, ballistic limits according to such a criterion as has been the Navy's cannot be expected to be determinable at obliquities of 20° or greater. Yet Navy ballistic limits on such plates at such obliquities have frequently been reported."

2. The above statement is based on reference (c), where referring to a particular type of equation for armor penetration, it is stated that the equation is subject to certain limitations, one of which is that the limit velocity must be the Navy limit, which is the velocity at which the complete projectile just passes through the plate and falls undeformed on the other side. The expression "Navy Limit" is not quite correct in this connection. The official definitions of limit velocity and complete penetration are defined in enclosure (A). It will be noted that on page 3, part two, the "Ballistic Limit" is defined as, "that striking velocity of a projectile which will permit the bullet to penetrate the plate and just fall behind it," without any reference to a requirement that the projectile be undeformed. On the contrary, on page 6, part two, of the enclosure, referring to the test of face-hardened armor, it is stated, "A complete penetration on this type of armor is therefore considered to be any through hole in the plate which would allow the major portion of the projectile to pass through the plate".

3. According to the definitions of "limit velocity" and "complete penetration" of reference (b), there is no inconsistency in reporting ballistic limits at obliquities where the projectiles break up. The statement in reference (a), quoted in paragraph 1, may cause confusion and misgivings on the part of contractors supplying armor under Navy specifications. It is therefore requested that the statement in reference (a) be clarified, and that the clarifying statement be distributed to all holders of reference (a).

G. F. HUSSEY, JR.

NA
CC: Watertown Arsenal
    NPG (With copy of ref. (a))

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Watertown Arsenal Laboratory
Experimental Report No. WAL 710/506
Final Report on Problem B-3.1 31 January 1944

AIRCRAFT ARMOR

An Empirical Approach to the

Efficient Design of Armor for Aircraft

OBJECT

To collate, integrate and analyze data concerning the ballistic characteristics of steel and lighter alloys and present the results in a form suitable for use by the designer and fabricator of aircraft armor.

SUMMARY

Known data concerning the ballistic characteristics of face-hardened steel, rolled homogeneous steel, duralumin and Dowmetal have been collated and analyzed. Wherever desired data have been scarce or non-existent, firings have been conducted to supply the necessary information.

Factors affecting the manner of failure of armor have been reviewed in an effort to explain the alternative superiority of different materials under different conditions of attack. It is apparent that, where the lower density of a material allows its use in thicker sections without additional weight, dimensional conditions arise favoring the ability of such a material to resist perforation. Thus duralumin which is only 0.36 times as dense as steel may overmatch an attacking projectile while an equivalent weight of steel may be overmatched by the same projectile. Under such conditions it is possible that the steel will require less projectile energy to bring about failure. The ability of a material to break up attacking projectiles is considered to be a potent factor in promoting one material's superiority over other materials.

Data have been tabulated and represented graphically, and by various superposition of these graphs estimates of the precise conditions under which one material surpasses others have been made. A graph enabling the designer to make a substantially accurate determination of the most efficient feasible design of armor has been drawn in Figure 21A.

The reactions of the several materials to shock, high velocity perforation and low temperatures have been discussed.

As a result of this study the following observations have been made:

1. Under no contemplated conditions will the use of rolled homogeneous steel or Dowmetal assure the maximum resistance (to perforation by small arms projectiles) per unit weight employed.

a. In general, when the obliquity of emplacement with respect to the anticipated line of fire is greater than 52°, or when the ratio of plate thickness (weighed) to projectile core diameter is less than 0.6, the use of 24ST duralumin will assure maximum resistance (to perforation by small arms projectiles) per unit weight employed.

b. Under all other conditions, the use of face-hardened steel armor will assure maximum resistance to perforation.

2. Under some conditions, the resistance (to shock) of rolled homogeneous steel armor is superior to that of face-hardened steel.

3. Except in the case of attack by direct impact of high explosive projectiles, the shock resistance of 24ST duralumin is equivalent to or better than that of steel.

4. Coincident with failure by perforation of armor-piercing projectiles, 24ST duralumin exhibits a tendency toward spalling.

5. Low temperature enhances the resistance to perforation of 24ST duralumin, rolled homogeneous steel and face-hardened steel.

6. Although low temperatures may affect deleteriously the shock resistance of steel, they apparently do not lower the shock resistance of duralumin.

7. Inasmuch as it is considered that resistance to perforation is of prime importance in any consideration of aircraft armor, design may well be based on observation 1.

8. The most strategic placement of armor will vary from time to time with the tactics of the opponent and contemporary design may best be decided on the basis of study of the very latest intelligence reports from the theaters of operations.

9. Under attack of projectiles of larger caliber, or different design or quality, the region of superiority of 24ST duralumin over face-hardened steel may be expected to be extended.

APPROVED:

H. H. ZORNIG
Colonel, Ord. Dept.
Director of Laboratory

J.F. Sullivan
Jr. Engineer

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PREFACE

In nearly every use of armor it is important that the maximum protection be afforded by the minimum expenditure of material.

Perhaps in no other application, however, is the object of getting the greatest protection from the least weight of armor of more importance than in the design and fabrication of aircraft armor. In the case of an aircraft, an increase in weight which, in some other application might be considered insignificant, may well affect its speed and maneuverability so adversely as to cause it to lose some tactical advantage which it might otherwise enjoy because of a favorable differential in these respects.

It is, therefore, of the utmost importance that designers and fabricators of aircraft armor be apprised of the ballistic characteristics of armor materials of various densities under variable conditions of attack so that they may more competently make decisions as to the proper selection and installation of aircraft armor materials.

It is to this end, then, that an attempt has been made in this work, authorized by the Office, Chief of Ordnance,[1] to collate, integrate and analyze available data of these types and to present the results of such analyses in a manner suitable for use by the designer or fabricator of aircraft armor.

INTRODUCTION

From time to time, and from several sources, there has arisen the contention that, on the basis of equal weights per unit surface area of armor employed, protection equivalent to that afforded by the traditional use of steel might be provided by materials of lighter alloy.

About a decade ago, Honda,[2] in a study of so-called "bullet-resisting" alloys, found that, of seven non-ferrous materials investigated, the aluminum alloy, duralumin, on the basis of weight for weight, offered greatest resistance to perforation by standard (cal. .25) Japanese ammunition.

Tests conducted at this arsenal[3] and at Aberdeen Proving Ground[4] revealed that, when used as components in composite armor assemblies, aluminum alloy sheets exhibited resistance characteristics comparable with those of steel in the same application.

In work conducted prior to 1938 at the Naval Research Laboratory[5] it was found that if plots of core limit energy per unit plate thickness were run versus hardness or versus ultimate tensile strength, a rough proportionality independent of large variations in plate density appeared. The fact that this study showed the inertia of the plate material to be of much less importance than hardness or ultimate tensile strength gave much greater credence to the contention that there might be developed a material of low density which would have ballistic characteristics comparable to those of steel.

Subsequent tests by the same laboratory[6] established that duralumin at high obliquities or at low incident velocities was superior, in resistance to perforation, to steel of equivalent weight per square foot.

Meanwhile, at this arsenal and at other test facilities there have been conducted several isolated ballistic tests[7-22] of materials of light alloy, but there has been apparently little correlation of the results of this work.

Simultaneously, there have been conducted tests (too numerous to recite) of face-hardened and rolled homogeneous armor of thicknesses feasible for use in aircraft, but, generally, the results have been of interest only insofar as they have served to answer some immediate problem and no greater correlation of these results seems to have been made.

NOTE: In the tabulation of data in this report m/d^3 is evaluated in terms of pounds-per-cubic-foot, but, in order to keep the expression e/d dimensionless, both e and d, as used in the latter ratio, are evaluated in terms of inches, since e is popularly evaluated in terms of inches.

In this work an attempt has been made to utilize the data disclosed by these several tests to the end that the relative protection afforded by the various materials may be estimated.

Several studies[23] have indicated that the aluminum alloy, duralumin, has good ballistic characteristics, and when a plot of energy per unit plate thickness (corrected for variations in density) was run versus hardness, on the basis of data in a Naval Research Laboratory Report,[24] it also appeared that, at a given hardness, equivalent weights per square foot of Dowmetal and steel might offer comparable resistance to perforation by small arms projectiles.

Rolled homogeneous armor of which the hardness range 340-380 BHN has been found most satisfactory over a wide range of variation of plate thickness and projectile caliber and design has lately been specified for use as aircraft armor and face-hardened steel has traditionally been used in such applications.

The resistance afforded by non-magnetic steel armor of gauges characteristic of aircraft armor is so much lower than that provided by magnetic steel armor that a review of its ballistic characteristics has been considered to be of no aid in the attainment of the ends of this study. Earlier work[25] has indicated that if non-magnetic properties are mandatory in an aircraft armor material, much more satisfactory resistance to perforation may be assured by the specification of a duralumin armor.

Thus, it has been decided, without fear of having neglected the investigation of any material which might afford substantially adequate protection from projectile impact, to confine this work to the study and comparison of the ballistic properties of face-hardened steel, rolled homogeneous steel (340-380 BHN), duralumin, and Dowmetal.

TEST PROCEDURE

Anyone who has conducted a search of the literature must admit of misgivings, at the conclusion of his search, concerning the percentage of data which may have escaped review by his method.

In that respect the present work is in no way unique inasmuch as many data extant may have remained concealed from the investigator whose resources of search have been limited by inconsistencies in the scope of dissemination of such information.

At the same time, many data discovered had to be disregarded for lack of faith in the methods of test procedure. For instance, studies at this arsenal[26] have indicated that at obliquities of 20° and greater it is virtually impossible for current small arms projectiles to perforate rolled homogeneous or face-hardened steel armor plate and remain intact. Complete penetration

according to the traditional Navy Limit criterion is attained when a projectile passes through the plate and remains intact.[27] Since a ballistic limit is not reached until complete penetration occurs, ballistic limits according to such a criterion as has been the Navy's cannot be expected to be determinable at obliquities of 20° or greater. Yet Navy ballistic limits on such plate at such obliquities have frequently been reported.

Since it was known that the Naval Research Laboratory, in view of the high incidence of small arms projectile breakage, had modified its criterion of failure,[28] when judging the results of tests made with such projectiles, to a standard similar to that used in determining the Lethal limit,[29] lately referred to as the Protection Ballistic Limit, it was decided to limit the use of data concerning Navy limits of face-hardened armor to reports emanating from that source or from sources known to employ a similar criterion.

Under such criteria, penetration is adjudged complete when a fragment of the projectile (or of the plate material) flies from the rear of the test plate with a force sufficient to cause it to pierce a sheet of light gauge aluminum alloy parallel to and a short distance behind the rear surface of the test plate.

The data on rolled homogeneous plate were known to be determined on the basis of similar criteria.

Since perforation of Dowmetal[30] and 24ST Duralumin[31] is effected almost exclusively without projectile breakage, the Navy limits of these materials, literally determined, are substantially indistinguishable from Lethal limits.

Thus curves drawn on the basis of such data would mark the borderline between protection and lack of protection from death-dealing missiles, and it is of vital importance that they be interpreted in this light. It is suggested that a substantial margin of safety be introduced by the designer translating these curves into practice.

Data thus collected have been separated according to plate material into Appendices A, B, C, and D, respectively, covering information concerning face-hardened steel, rolled homogeneous steel, duralumin, and Dowmetal.

(Although the ballistic characteristics of several aluminum alloys and magnesium alloys have been listed in Appendices C and D, the comparison of the ballistic characteristics of duralumin and Dowmetal with those of rolled homogeneous and face-hardened steel has been based on the results of firings of 24ST duralumin and Dowmetal (FS) respectively, which have exhibited in the past the best all-round ballistic characteristics of their respective types. The generic use of the terms "duralumin" and "Dowmetal" throughout this report should be interpreted in this light.)

Within each table these data have been arranged according to the ascending order of the obliquity of incidence and, in those cases where the obliquity is common, in the ascending order of the ratio of plate thickness (e),

in feet, corrected to the thickness of steel of equivalent weight per square foot (e_1)*, to projectile core diameter (d), in feet.

Additional characteristics listed in these tables are: a form factor ($m/d3$), in which (m) is the weight of the projectile core in pounds and (d) is its diameter in feet; a measure of the amount of material (taking into account oblique emplacement) necessary to shield a unit area normal to the line of fire ($e_1/d \cos \theta$, where θ is the angle of obliquity (deviation from normal) of emplacement); and a measure of ballistic merit, the Thompson Coefficient, (F)†.

Data sources have been symbolized in these tables but are explained in a note elsewhere in this report.‡

In Figures 1 to 4 of each Appendix, the Thompson Coefficients (F) have been plotted versus the ratios of plate thickness (e), corrected to the thickness of steel of equivalent weight per unit surface area (e_1), to the projectile core diameter (d), with allowance for the greater area of obliquely installed material necessary to shield a unit area normal to the line of fire ($e_1/d \cos \theta$)**.

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* Factors used in this report for conversion of (e) to (e_1) are as follows:

Face hardened and rolled homogeneous steel	$e_1 = e$
Duralumin	$e_1 = \frac{e}{2.8}$
Dowmetal	$e_1 = \frac{e}{4.4}$

† In this report consideration of the variation in densities of the different materials dictates the use of the following formula:

$$F = \frac{m V^2 \cos^2 0}{e_1 d^2}$$

with V, the limit of resistance to perforation (in this study substantially the lethal limit) and the other symbols as above.

‡ See Appendix F. Explanation of abbreviations.

** In order to shield an equivalent area normal to the line of fire it is necessary to employ a greater area of armor the more obliquely this armor is installed. Thus at 60°, twice the area of armor is required to protect the same area normal to the line of fire as is required of armor normally installed. (See Figure 1B).

In Figures 5 to 8 of each Appendix the limits of resistance to perforation (V_N or V_L) have been plotted against a similar axis.

The graphs of these plots form a basis for the several figures in the body of the report.

Figure 1 has been drawn to provide a nomographic method of ready conversion from values of ($e_1/d \cos \theta$) or (e_1/d) to actual thicknesses of the different materials under impact of cal. .30 A.P. M2 or cal. .50 A.P. M2 projectiles.

Figure 1A attempts to depict graphically the difference in thickness of the different materials of equal weight which results from their variant densities.

Figure 1B illustrates the necessity of using a greater area of armor obliquely emplaced to protect a fixed area normal to the line of fire.

Figure 1C shows how a variation in the ratio of plate thickness (e) to projectile core diameter (d) tends to influence the manner in which plate failure will occur.

In Figures 2 to 5, (F) is shown as a function of ($e_1/d \cos \theta$) and obliquity for each material. In Figures 6 to 9, obliquity (0°, 30°, 45°, 60°) is held constant and (F) is shown as a function of ($e_1/d \cos \theta$) and plate material.

Figures 10 to 13 and 14 to 17 repeat the pattern of Figures 2 to 5 and 6 to 9 with the limit of resistance to perforation (V_N) substituted for (F).

On the basis of Figures 10, 11, 12, and 13 (or with equal validity Figures 14, 15, 16, and 17) Figures 18, 19, 20, and 21, respectively, have been drawn to represent the conditions with respect to obliquity of emplacement and the ratio of plate thickness (weighted) to projectile core diameter necessary to provide protection against lethal damage resulting from projectile impact of various striking velocities, when different armor materials are used.

By comparison of Figures 18 to 21 the conditions under which greater or less protection from such damage can be expected from the use of the different materials may be determined and these are shown from the viewpoint of the use of the respective materials in Figures 22 to 25.

Consideration of Figures 18 to 25 indicates qualitatively conditions under which the use of a particular material will provide maximum protection. These conditions are represented in Figure 21A and the axis ($e_1/d \cos \theta$) has been substituted for (e_1/d) in order to illustrate the exact conditions under which the most efficient use of armor may be made.

On the basis of Figures 18 to 21, half-areas of vulnerability to be expected from the use of the various materials under conditions where the ratio of plate thickness (weighted) to projectile core diameter is equal to 0.6, 0.8, 1.0 and 1.2 have been drawn in Figures 26, 27, 28 and 29 respectively.

In Figure 30 the area of vulnerability typical of the use of each material as armor is shown as a function of the ratio of plate thickness (weighted) to projectile core diameter (e_1/d).

Relevant ballistic test results, heretofore unpublished have been set forth in ballistic data sheets in the appropriate appendices.

RESULTS AND DISCUSSION

The pathway to a valid analysis of ballistic test data is often beset with the many pitfalls incidental to the variable nature of ballistic testing.

Generally speaking, the simultaneous presence of so many interrelated variables, many of which are incapable of precise quantitative evaluation, renders fruitless any effort to assess them independently on the basis of empirical evidence.

However, it is believed that the quasi-statistical nature of the data in this report will tend to frustrate any wayward trends and that the results of this study will be substantially free from the bias of any such variables.

A. Resistance to Perforation

1. Effects of Plate Hardness on Resistance to Perforation by Current Small Arms Projectiles

In the case of a given material, perhaps no other single characteristic, except thickness, has a greater effect upon its ability to withstand perforation than its hardness. A study, previously cited,[32] of materials of various density, showed a remarkable correlation between hardness and resistance to perforation independent of the densities of the materials involved.

At first glance this might suggest that comparable optimum ballistic results may be obtained from equal thicknesses of materials of wide density variation, which in turn would indicate the use of the lightest material, thus effecting the greatest saving in weight. Indeed there might be some validity to such a thought if the lighter alloy materials could be made as hard as steel.

Unfortunately, however, there exists, in the case of each material, and even in the case of each alloy of a single material a critical hardness beyond which no treatment will carry it and long before this critical hardness is approached another critical hardness is reached which may not be surpassed without introducing into the material characteristics of brittleness which are seriously deleterious to its ballistic behavior.

Since, in the cases of the materials discussed herein, there seems to be a rough proportionality between this latter limit and the density of the material, it is apparent that hope of securing comparable ballistic characteristics from equivalent weights of materials of variant density cannot lie in elevating the hardness of the lighter alloys to the level of that of steel but rather must proceed from some advantage which may emanate from the increase in thickness without an increase in weight, allowable by the lower density of these alloys. It is in this light, then, that a consideration of the mechanisms of perforation is relevant.

2. Mechanisms of Perforation of Armor

There are two extreme types of mechanism by means of which armor may be perforated.[53] The more common type of perforation is accomplished by the projectile's plastically pushing aside the plate material in its path until a hole has been formed sufficient to allow its passage through the plate. This mechanism, substantially, is characteristic of the perforation, at normal incidence, of soft armor by sharp-nosed undermatching non-deforming projectiles.

The other extreme is characterized by the plate's failure in shear along a nearly cylindrical surface perpendicular to the plane of the plate surfaces, resulting in the release from the path of the projectile of a nearly cylindrical plug, thus facilitating the projectile's progress through the plate. This mechanism is typical of the perforation at normal incidence of a hard plate by a greatly overmatching flat-nosed projectile.

Variations in the design, composition, heat treatment and hardness of the projectile, variations in the composition, heat treatment, hardness and soundness of the armor, variations in the ratio of plate thickness to projectile core diameter and variations in the obliquity of incidence will tend to produce various combinations of these two basic mechanisms, the initial stages of such failures occurring by way of plastic deformation and eventual failure occurring in shear.

In general, failure in shear will occur with a smaller absorption of projectile energy per unit volume displaced than in plastic failure. Thus, if conditions are otherwise the same, it might be expected that a plate which would tend to fail plastically would more greatly resist perforation by a given projectile than one which tended to fail in shear.

Figure 1A shows the difference in thickness of equal weights of steel, duralumin and Dowmetal of equal surface area.

Figure 1C shows the conditions with relation to plate thickness and projectile core diameter under which shear failure and plastic failure tend to occur.

Consideration of these two figures leads one to contend that under conditions where an equal weight of two different materials would result in the projectile's overmatching one (and thus tending to produce a shear failure) and undermatching the other (and thus tending to produce plastic failure) the resistance of the lower density material would be expected to be much greater. This might, indeed, be the case, if equivalent physical properties, especially hardness, could be obtained in the low density materials. As previously mentioned, of course, the maximum hardness obtainable in the lighter alloys is considerably below that of steel but, as it will develop later in this report if the steel is sufficiently overmatched while the duralumin, of a reasonable hardness, still is undermatched, the different mechanism of failure will enable the lighter alloy to resist perforation at a higher velocity than steel can, in spite of the hardness differential.

In the past, graphs of the Thompson Coefficient (F) versus the ratio of plate thickness to projectile core diameter have been helpful in allowing an anlysis of the mechanisms characteristic of different ratios of these two measurements. In order to facilitate a comparison of the ballistic efficiencies of equivalent weights of different materials shielding a unit area normal to the line of fire, the (e/d) axis has been adjusted in this report to ($e_1/d \cos \theta$).

Thus a plot of (F) values based on perforations at normal incidence effected purely by a plastic pushing aside of material of constant physical properties from the path of a non-deforming projectile might be expected to result in a horizontal path where, at all values of e/d (or of $e_1/d \cos \theta$), (F) would be the same.[34]

On the other hand, perforations at normal incidence effected predominantly by failure of the plate in shear might be expected to produce (F) values tending to fall in a steep curve sloping sharply downward as (e/d) decreased.[35]

For the purpose of comparing the types of failure characteristic of the different materials at common values of ($e_1/d \cos \theta$), plots of (F) versus this parameter have been drawn in Figures 1 to 4 of each appendix which have been superimposed in various combination in Figures 2 to 9 of the body of the report.

a. Face-Hardened Steel (Figure 2 and Appendix A, Figures 1 to 4).

Figure 1 of Appendix A shows a trend of (F) values characteristic, at values of ($e_1/d \cos \theta$) less than 0.8, of material which fails in shear. Above this value, the trend is similar to that of plastic failure.

The factor of projectile breakage in the attack of face-hardened plate has done much to obscure the mechanism of failure of this type of armor and it is outside the scope of this study to determine the precise mechanism by which this material fails. However, visual examination of perforations of this material indicates a high tendency for it to fail in shear even at high values of (e/d). It has been shown[36] that the release of the plug formed by the failure of the material in shear becomes more difficult when the plate thickness (e) exceeds the diameter of the projectile core (d). This plug tends to have limiting dimensions of (d) x (d) and thus when (e) exceeds (d) the shearing does not propagate to the rear surface of the plate and this final layer of material may either bend back or break out to release the plug.

Whatever the exact mechanism is, its effect upon the amount of energy necessary to carry it to its conclusion is of more importance, from the viewpoint of this discussion.

Sudden changes in the direction of these graphs indicate at least a change in the increment or decrement of energy necessary to displace unit volumes of material in the projectile's path and may be interpreted as indicative of changes in the predominant mechanism type.

Thus in the case of face-hardened steel at normal incidence, below values of ($e_1/d \cos \theta$) of 0.8, it is reasonable to assume that some mechanism takes place requiring considerably less energy per unit volume displaced to effect perforation as (e/d) decreases. At values of ($e_1/d \cos \theta$) in excess of this figure, the increment rate of energy per unit volume of plate material displaced required to effect perforation appears to be considerably less than below the critical value and it may be reasonable to conclude that this difference is attributable to a change in the predominant mechanism.

Similar changes in trend are noticeable at obliquities of 30° and 45°, but at 60° only a single general trend is apparent. This is probably due to the fact that at 60° obliquity the actual (e/d) of the highest ($e_1/d \cos \theta$) value is less than unity and under such circumstances shear failure probably predominates in all cases.

b. Rolled Homogeneous Steel. (Figures 3 and Appendix B, Figures 1 to 4).

At normal obliquity the data takes the course which might be expected of (F) values resultant from predominantly plastic failure. From experience it may be stated that at values of (e/d) less than those treated in Figure 1 of Appendix B, (F) falls off rapidly in a manner similar to that of Figure 1 of Appendix A. Such would be the course expected of (F) values resulting from failure predominantly in shear.

At obliquities of 30° and 45° the trend, as (e/d) increases, is a gradual one from predominance in shear failure to predominance in plastic failure.

The indications of these graphical trends as to the predominating mechanism are borne out in a visual examination of the perforations.

At 60° obliquity the data are too sparse to be considered significant.

c. Duralumin. (Figure 4 and Appendix C, Figures 1 to 4).

At normal incidence and at all obliquities, when ($e_1/d \cos \theta$) equals 0.6 or more, the trend of the data indicates predominantly plastic failure.

At 60° obliquity, at values of ($e_1/d \cos \theta$) less than 0.6, the change in the trend of the data may be interpreted as indicative of predominantly shear failure. This is to be expected because under those circumstances (e/d) is actually about 0.9 and even this softer material might be expected to fail in such a manner when it is overmatched. If allowance for the difference in density of the two materials is made, it will be apparent that the slopes of this section of the 60° duralumin graph and that of the entire 60° face-hardened steel graph are quite similar and for the same reason.

d. Dowmetal (Figure 5 and Appendix D, Figures 1 to 4).

Since under no conditions of testing were any of the Dowmetal plates overmatched, failure of this material occurred always predominantly plastically and graphs of the resultant data assume the anticipated course.

e. Comparison of Materials. (Figures 6 to 9).

Considering only that section of the graphs in Figure 6 where they tend to be horizontal, the greatest efficiency at normal incidence results from the use of face-hardened steel, followed by duralumin, rolled homogeneous steel and Dowmetal. This is doubtless due to the ability of the face-hardened armor, because of its superior hardness, to fracture the projectile and thus hinder its efficient operation of perforation. Duralumin apparently has sufficient hardness coupled with its greater thickness (2.8 times that of an equivalent weight of steel) to enable it to provide a more serious obstacle than rolled homogeneous steel to the projectile's progress. Dowmetal, however, in spite of still greater thickness (4.4 times that of an equivalent weight of steel) apparently does not have sufficient hardness to enable it to exploit its thickness adequately.

At values of $(e_1/d \cos \theta)$ less than 0.8 the tendency of (F) values for duralumin and Dowmetal to remain unchanged while (F) values of the two steel armors fall off sharply due to their overmatching the attacking projectiles while the steels are overmatched can be seen in this figure. At obliquities, the conditions where steel is overmatched by the attacking projectiles while the lighter alloys overmatch the projectile occur at higher values of $(e_1/d \cos \theta)$ and will be seen to increase the frequency of situations where the use of the lighter alloys will be of advantage.

At 30° obliquity (Figure 7) rolled homogeneous plate enjoys a temporary superiority over duralumin, because its hardness is sufficient to cause a greater deflection of the projectile thus increasing the bending moment to a point where projectile failure will occur. The hardness of duralumin is insufficient to influence projectile breakage even at obliquity but inasmuch as its hardness is greater than that of Dowmetal it maintains a superiority over that material even though their mechanisms of failure are similar and the Dowmetal con. erably thicker.

The point at which the lighter alloys attain an advantage over the steels occurs at a greater value of $(e_1/d \cos \theta)$ at this obliquity (30°) than at normal incidence, and as obliquity increases (Figures 8 and 9) at even higher values until at 60° duralumin has the advantage over both types of steel throughout the entire range of striking velocity investigated.

The advantage gained by the more favorable plastic mechanism of failure which flows from the thickness differential may be appreciated from an examination of Figure 9 wherein the duralumin, failing in shear at values of $(e_1/d \cos \theta)$ lower than 0.6 because of its low actual (e/d) ratio, falls below Dowmetal which, because of its lower density, still overmatches the projectile at these values.

3. Limits of Resistance to Perforation

In Figures 5 to 8 of the appropriate appendices, plots of the limits of resistance to perforation versus $(e_1/d \cos \theta)$ have been run. These are fundamental graphs and are presented to illustrate the fit of the curves to the data. No especial refinements of curve fitting have been attempted. These graphs, in various combination, have been represented in Figures 10 to 17 of the body of this report. It is to the latter group of figures that attention may well be directed.

The presentation of data with (V_N) as a function of $(e_1/d \cos \theta)$ is a logical one in an investigation of the efficient use of weight in armoring structures in that it facilitates a portrayal of the efficiency (in terms of resistance to perforation) of equal weights of materials of various density installed at various obliquities to the line of fire, all of which are capable of shielding the same area normal to the line of fire.

Thus a single unit of thickness of a given material installed at 60° must offer resistance to penetration equal to that of two units of the same material installed at normal incidence if it is to be considered equally efficient, since twice the area of armor installed at 60° obliquity is required to protect the same area as is required of armor installed normally. Likewise at any given angle of installation a single unit of thickness of one material should offer resistance equal to that afforded by two thickness units of a material half as dense if it is to be adjudged equally efficient.

Such information should be invaluable to the designer who has a given area normal to the line of fire for which he must provide protection against a given projectile with a minimum extravagance of armor weight.

Figures 10 to 17 may be entered at the velocity against which protection is required and the material and obliquity determined which will provide this protection with the least expenditure of weight, since if the attacking projectile is known then so is (d), and ($e_1/d \cos \theta$) then becomes virtually an expression of the weight necessary to provide protection to a unit area normal to the line of fire.

a. Face-Hardened Steel. (Figure 10 and Appendix A, Figures 5 to 8.)

These figures indicate that if face-hardened armor is to be used at one of the four obliquities considered, maximum efficiency will be had from its use at normal incidence when ($e_1/d \cos \theta$) equals 0.45 to 0.9, at 45° obliquity when ($e_1/d \cos \theta$) equals 0.9 to 1.42 and at 60° obliquity when this value exceeds 1.42.

b. Rolled Homogeneous Steel. (Figure 11 and Appendix B, Figures 5 to 8.)

These figures indicate that, if rolled homogeneous steel is desired to be used at one of these obliquities, its most efficient use will occur at normal incidence when ($e_1/d \cos \theta$) is less than 0.7 and at 60° obliquity when this measure is greater than 1.1. On the basis of these curves it is impossible to determine whether maximum efficiency will result from its use at 45° obliquity or at 60° obliquity when ($e_1/d \cos \theta$) lies between 0.7 and 1.1.

c. Duralumin and Dowmetal. (Figures 12 and 13 and Appendices C and D, Figures 5 to 8.)

These curves indicate that generally the most efficient use of the two light alloys may be made at 60° obliquity, although at extremely low values of ($e_1/d \cos \theta$) more efficient use might be expected from their normal emplacement.

d. Normal Incidence. (Figure 14.)

If design considerations dictate the use of an armor at normal incidence a consideration of these curves indicates, that unless the value of ($e_1/d \cos \theta$) is less than 0.62 (in which situation duralumin should be used) maximum efficiency will be realized from the use of face-hardened steel.

e. Obliquity - 30°. (Figure 15.)

If installation at this obliquity is contemplated, the use of duralumin where ($e_1/d \cos \theta$) is less than 0.67 and the use of face-hardened steel where this value is greater will yield the maximum efficiency.

f. Obliquity - 45°. (Figure 16.)

At this obliquity of installation, the use of duralumin at values of ($e_1/d \cos \theta$) up to 0.8 and the use of face-hardened steel above this figure appears to be most efficient.

g. Obliquity - 60°. (Figure 17.)

At this obliquity the use of duralumin at all values of ($e_1/d \cos \theta$) is probably most efficient although at extremely low values of this measure there exists some basis for the use of Dowmetal.

4. Protection from Projectiles of Given Striking Velocity (Figures 18 to 25).

The figures reviewed immediately above are perhaps relevant only when installation is contemplated at one of the four obliquities (0°, 30°, 45°, 60°) specifically investigated. The more usual situation encountered by the designer is apt to arise when protection against a particular projectile at a given striking velocity (or range) is specified.

It is to aid in a solution of such a problem that Figures 18 to 21 and Figures 22 to 25 have been plotted.

From Figures 18 to 21 the appropriate combination of plate thickness and obliquity of emplacement to provide protection against a given projectile at any striking velocity may be estimated for any of the four materials under investigation. In interpreting these curves the use of Figure 1 may be expected to be of help.

Figures 22 to 25 show the relative efficiencies of the different materials under conditions of varying obliquity and weight per unit area protected. From a consideration of these figures it is obvious that maximum efficiency will never be realized from the use of rolled homogeneous steel

or Dowmetal. The curve at the left of Figure 24 will be seen to indicate the line of demarcation between the conditions under which the use of duralumin is most efficient and those conditions under which the use of face-hardened steel is most efficient of all four materials under analysis. Roughly speaking, when the obliquity of installation is to be 52° or greater, or when the ratio of plate thickness (weighted) to projectile core diameter (e_1/d) equals 0.6 or less, the use of duralumin will produce the maximum protection per unit weight employed, and under all other conditions, this maximum efficiency will proceed from the use of face-hardened steel.

These figures (22 to 25) thus indicate qualitatively the conditions under which the most efficient design f aircraft armor installations may be made. In order to represent these conditions quantitatively, Figure 21A has been prepared.

In this figure the axis ($e_1/d \cos \theta$) has been substituted for the (e_1/d) axes of Figures 18 to 25. This has been done because ($e_1/d \cos \theta$) in essence represents the weight of armor necessary to protect a unit area normal to the line of fire, and takes into consideration the greater area of obliquely installed armor necessary to provide protection to an equivalent area.

Thus where equivalent protection (as represented by the curves for different striking velocities) may be obtained from a lower value of ($e_1/d \cos \theta$), more efficient use of armor may be enjoyed by installing it at the indicated obliquity. Figure 1 will prove to be very helpful in translating the indications of these curves into units of actual thickness of the different materials under impact of each of the two projectiles.

The most striking indication of Figure 21A is that the maximum efficiency over the entire range of obliquity from 0° to 60° will be enjoyed from the use of duralumin at 60° obliquity. Thus, if the only factor to be considered in the design of aircraft armor were weight, the problem would be a simple one. "Install duralumin at 60° obliquity" would be the panacean answer.

However, armor is perhaps more of a luxury than an essential according to current design philosophy and, in any event, the designer probably finds himself restricted to small ranges of obliquity of installation with respect to the most probable line of fire. In such a situation he may turn hopefully to Figure 21A.

Now if he must protect against perforation at striking velocities in excess of 2100 feet per second and is restricted by other design considerations within a specific range of obliquities of installation he may generally assure himself maximum efficiency by installing the appropriate material at the highest obliquity within that range. If, on the other hand, impact is anticipated at lower velocities, maximum efficiency will generally proceed from the emplacement of armor normal to the line of fire, although even at low velocities emplacement at obliquities greater than 45° may be more efficient.

In any event, these curves (used in connection with Figure 1) will assist the designer in estimating the protection to be expected from the use of various thicknesses of different armor materials at various obliquities and by determining that obliquity (within the range of allowable obliquities) at which the desired protection may be provided with the least expenditure of weight,--that is, the lowest value of ($e_1/d \cos \theta$)--he may more confidently specify the most efficient obliquity of installation.

The change in the efficiency of oblique installation of armor as the limit striking velocity diminishes may have some explanation in the following observations.

With a given material, the resistance to perforation by a given projectile may, in the first analysis, be expected to be a function of the thickness of the plate, or, in other words, the length of the path that the projectile must travel to pass through the plate.

Thus, at obliquity, we might expect the increase in resistance to perforation to reflect the increased length which the projectile must travel because of the tilting of the plate. Naively, this increased path might be expected to be inversely proportional to the cosine of the angle of tilting. However, in the case of current small arms projectiles, when the plate is thicker than the diameter of the projectile core, the projectile upon oblique impact is deflected away from the normal so that the effective path is greater than would be expected from a mere consideration of the cosine function. The length of the path thus increases at a greater rate than the area necessary to shield a unit area normal to the line of fire and an advantage in using armor at a higher obliquity under these circumstances might reasonably be anticipated.

On the other hand, when the armor is overmatched by the projectile, the plate tends to fail in shear and the release of a plug from the path of the projectile influences the deflection of the projectile towards the normal thus effectually shortening its expected path through the plate and introducing a reasonable expectancy of disadvantage in the use of such material at obliquity.

However, when plate and projectile match there tends to be an initial deflection away from the normal followed by a punching failure of the plate which deflects the projectile toward the normal with the cumulative length of the path roughly equivalent to that indicated by reference to the cosine function. Thus, it develops, obliquity tends to have little effect upon protection per unit weight employed when ($e_1/d \cos \theta$) approximates unity.

It will be noticed that these curves have not been extended to obliquities beyond 60°. This restriction has been due in some part to the scarcity of data at those obliquities, but in no small way has it been the result of a recognition that the area of armor necessary at such obliquities to provide a screen for a given area normal to the line of fire is so great

that the thinness of armor necessary to keep the overall weight constant is such as to render operative a law of diminishing returns as to the protection provided per unit weight employed.

5. Areas of Vulnerability.

If a given thickness of armor material is attacked from various angles, it will readily be anticipated that the nearer normal the angle of attack, the greater the range from which the projectile may be propelled at a given muzzle velocity and perforate the plate, and the more oblique the angle of attack is, the shorter the effective range will become until at a critical obliquity even a point blank attack would be repelled.

From a consideration of the data in this report, a translation of this qualitative observation into much more quantitative terms may be made.

Thus, in Figures 26 to 29, half-areas of vulnerability for each of the four materials have been drawn for conditions where the ratio of plate thickness (weighted) to projectile core diameter is equal respectively to 0.6, 0.8, 1.0 and 1.2. We may then observe how the shape and extent of these areas of vulnerability are effected by changes in this ratio.

These figures signify the areas within which a caliber .50 gun with muzzle velocity of 2950 feet per second may be set up with respect to the position of the armor and propel caliber .50 A.P. M2 projectiles which will perforate armor of various materials equivalent in weight to .257", .343", .429" and .514" of steel respectively. With respect to aircraft combat these areas would effectively represent cross sections of volumes of vulnerability inasmuch as the aerial theater is virtually a three dimensional proposition.

It will be noticed that as the thickness of the armor increases the areas of vulnerability of the steels, especially those of face-hardened steel, diminish at a much greater rate than those of the lighter alloys. This trend is represented graphically in Figure 30.

However, the shapes of the areas are probably of greater significance from the standpoint of tactics. Thus a wide flat area would signify greater invulnerability from attack at normal incidence but would allow a greater panorama of lethal attack than a long narrow area. The shape is, therefore, significant since attack may frequently come from angles other than the expected one on which design has been based.

6. Extrapolability of Trends Indicated by These Data

A question may well be posed as to the extrapolability of the conclusions drawn from data based upon firings of caliber .30 A.P. M2 and caliber .50 A.P. M2 projectile attack to situations where attack is expected from projectiles of larger caliber or different design or quality.

Examination of the methods by which the different materials defeated the attacking projectiles is believed to be relevant to an answer to this question. In the case of Dowmetal no projectile fracture has been observed during the tests conducted at this arsenal. In the case of duralumin, projectile breakage has been so rare as to be considered negligible. In the case of rolled homogeneous steel, projectile breakage has been the rule when the test obliquity has been 20° or greater. In the case of face-hardened steel, the recovery of an intact projectile has been extremely rare under any conditions. It thus seems reasonable to attribute the superiority of face-hardened steel over the lighter alloys in some measure to the ability of the steel to break up the projectile and thus hinder its efficient function as a perforater.

If, therefore, conditions should be translated into a sphere where projectile breakage against steel is rare, as in the case of larger calibers, the steel might be expected to lose some of its success in overcoming projectile attack and the regions where duralumin is superior to face-hardened steel might reasonably be expected to be extended.

Similarly, the shape of current small arms projectiles is such as to promote their deformation and fracture under oblique attack and an improvement in design or quality could be expected to diminish the ability of steel armor to withstand their attack whereas the performance of duralumin (or Dowmetal), accomplished without the aid of projectile breakage, may reasonably be expected to be unaffected by such changes.

Thus any extrapolation of the conclusions of this study should be attended by a recognition of the contention that in those situations wherein the margin of superiority of face-hardened steel over duralumin is slim, small changes in the caliber, design or quality of the projectile may be sufficient to obliterate the difference.

B. Shock Properties

If resistance to perforation were the sole consideration in the selection and design of armor, this study might well be concluded forthwith. However, the behavior of armor under shock and high velocity perforation are considerations not to be disregarded.

Data concerning these characteristics are, however, not abundant and for this section of the report information will be drawn largely from a recent report[37] of the Naval Proving Ground with which past experience at this arsenal has been consistent.

1. 20 mm, H.E. Projectiles

The high-explosive projectile, if it reaches the principal armor prior to detonation, imparts to the armor a shock consisting simultaneously of the effect of the projectile impact plus the forces generated by the detonation

of the explosive charge. The severity of the effect of the latter is a function of the distance of the explosion from the surface of the plate.

Thus, if the time lag between impact and detonation is constant and the position of the explosive charge within the projectile is fixed, it might be expected that against a softer material the projectile, upon impact, would penetrate more deeply prior to detonation and at the time of explosion the charge would be closer to the plate surface and the effect consequently more severe. Similarly if the explosive charge is situated nearer the nose of the projectile the effect would be expected to be more severe.

In order to combat the attack of this type of projectile, then, a material must be hard enough to resist penetration of the projectile yet ductile enough to withstand the distortional effects of the explosive force.

Thus, tests reported by the Naval Proving Ground have shown that against attack with 20 mm. H.E. projectiles at 20° obliquity rolled homogeneous steel is superior to face-hardened steel which, in turn, is superior to 24ST duralumin. These tests, however, simulate conditions where the armor would be the first substantial obstacle in the path of the projectile. In service, this situation would rarely arise because the skin of the aircraft would usually be sufficient to detonate the charge prior to impact upon the principal armor. Under conditions where explosion took place at a distance greater than a few inches from the plate, it is difficult to visualize the resultant failure of armor plate.

This same report indicates that against fragments of 5" anti-aircraft shells, 24ST duralumin is equivalent to rolled homogeneous steel and slightly superior to face-hardened steel.

2. Impact of Yawed Projectiles

Much aircraft armor is installed in interior positions. Attack of such armor then is seldom direct and projectiles frequently encounter other obstacles before impacting the armor. As the projectile defeats these primary obstacles, it is likely to be tumbled and its impact against the armor is unlikely to be nose-on. This attitude of attack of the projectile subjects the plate to a combination of penetration and shock and, because the yawed impact of the projectile effectually increases in one dimension the projectile diameter of the core, there is accentuated any tendency of the plate to fail in shear.

The ability of armor materials to withstand this method of attack is, therefore, of relevance to a study of aircraft armor.

Tests at the Naval Proving Ground consistent with observations made at this arsenal indicate that under attack of yawed caliber .50 A.P. M2 projectiles, 24ST duralumin is superior to both face-hardened and rolled homogeneous steel.

C. High Velocity Perforation

When a projectile passes through the plate at a velocity well in excess of the limit of resistance to perforation, there are set in motion within the plate forces which are conducive to the release of plate fragments coincident with the projectile's exit from the plate, if the plate is of inferior structural quality. The size and shape of these fragments are often such as to possess more potential lethality than the projectile itself.

Ballistic specifications have been established for rolled homogeneous and face-hardened steel armor which largely eliminate the possibility of the procurement of steel armor which will fail in this manner.

24ST Duralumin (see Figure 31) and Dowmetal, however have, in the course of development tests, shown a tendency to fail in this manner upon complete perforation. It is difficult to predict whether this tendency could be eliminated so that ballistic specifications might be established which would assure the procurement of lighter alloy armor with characteristics comparable to current steel armor under conditions of high velocity perforation.

D. Effects of Low Temperatures

During aerial combat the ambient temperatures are frequently greatly less than zero. The behavior of armor under impact at these low temperatures is, therefore, of interest in a consideration of aircraft armor.

Relatively few ballistic tests of armor have been conducted at low temperatures but those that have been conducted have indicated that the decline in temperature enhances somewhat the resistance to perforation of 24ST duralumin[38] and steel.[39]

On the other hand, extensive tests have shown that the impact properties of steel are reduced by decreasing temperatures[40] whereas the impact properties of duralumin actually increase below zero.[41] Impact properties have been shown to have a close correlation with resistance to shock.[42] Thus the shock resistance of steel is somewhat decreased by sub-zero temperatures[43] while it may reasonably be expected that the shock resistance of duralumin will not be affected deleteriously by a reduction in temperature.

E. General Considerations

Controversy will always be rife as to the relative importance of superiority in resistance to perforation and superiority in resistance to shock where there is a difference in these two attributes. The conclusions of this report will evolve from the contention that, unless a material's resistance to shock is grievously inferior, the prime consideration in the selection of aircraft armor material should be its ability to resist perforation.

Consideration of the most strategic placement of armor throughout an aircraft has not been made a part of this study because it is felt that such

considerations are sensitive to the variable tactics of the enemy and more competent information concerning this phase of design may be garnered from an up-to-the-minute survey of intelligence reports from the appropriate theaters of operations.

F. Summary of Results and Discussion

From the foregoing discussion the following observations may be made:

1. Under no contemplated conditions will the use of rolled homogeneous steel or Dowmetal assure the maximum resistance (to perforation by small arms projectiles) per unit weight employed.

a. In general, when the obliquity of emplacement with respect to the anticipated line of fire is greater than 52°, or when the ratio of plate thickness (weighed) to projectile core diameter is less than 0.6, the use of 24ST duralumin will assure maximum resistance (to perforation by small arms projectiles) per unit weight employed.

b. Under all other conditions, the use of face-hardened steel armor will assure maximum resistance to perforation.

2. Under some conditions, the resistance (to shock) of rolled homogeneous steel armor is superior to that of face-hardened steel.

3. Except in the case of attack by direct impact of high explosive projectiles, the shock resistance of 24ST duralumin is equivalent to or better than that of steel.

4. Coincident with failure by perforation of armor piercing projectiles, 24ST duralumin exhibits a tendency toward spalling.

5. Low temperature enhances the resistance to perforation of 24ST duralumin, rolled homogeneous steel and face-hardened steel.

6. Although low temperatures may affect deleteriously the shock resistance of steel, they apparently do not lower the shock resistance of duralumin.

7. Inasmuch as it is considered that resistance to perforation is of prime importance in any consideration of aircraft armor design may well be based on observation 1.

8. The most strategic placement of armor will vary from time to time with the tactics of the opponents and contemporary design may best be decided on the basis of study of the very latest intelligence reports from the theaters of operations.

9. Under attack of projectiles of larger caliber, or different design or quality, the region of superiority of 24ST duralumin over face-hardened steel may be expected to be extended.

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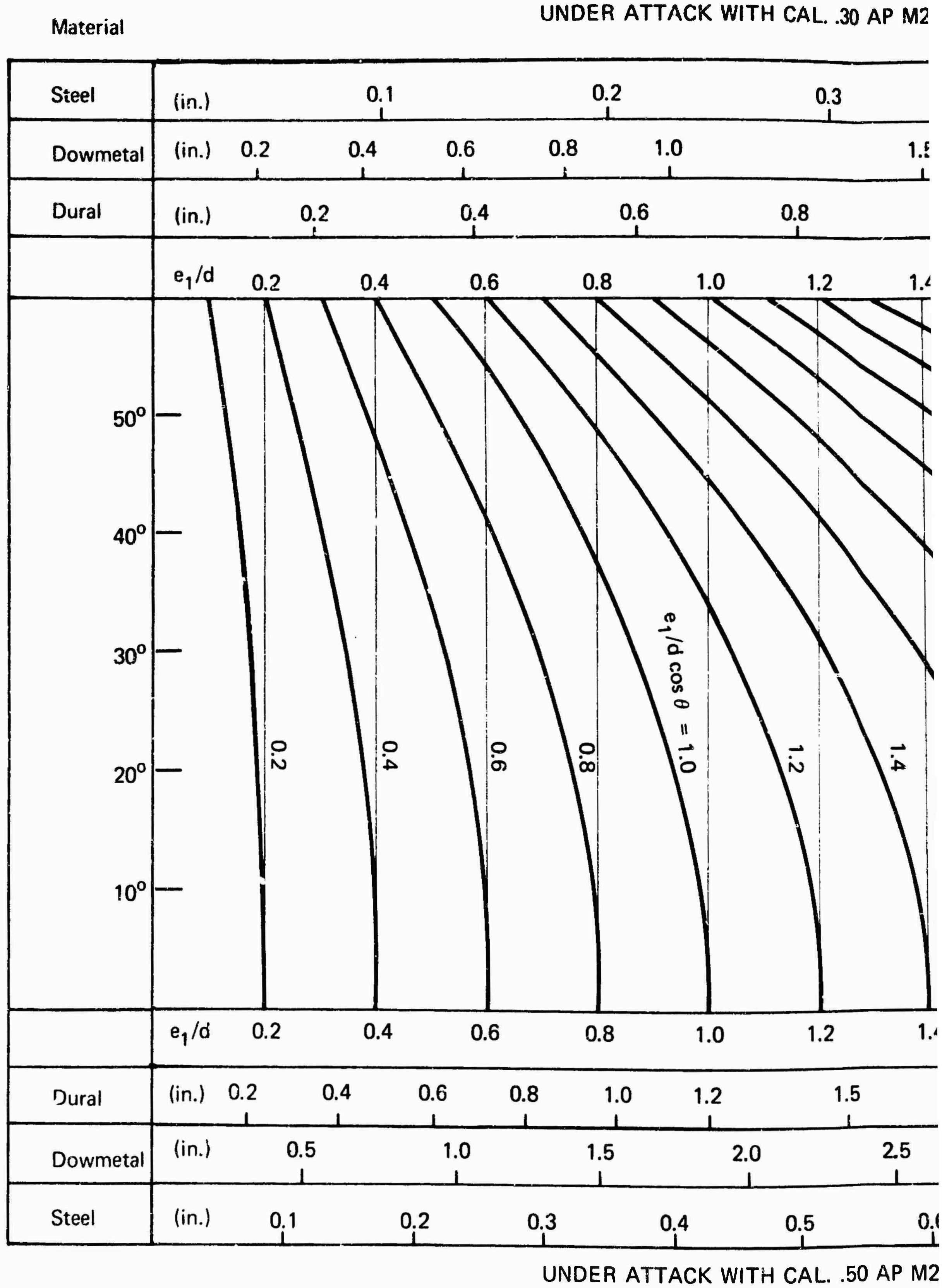
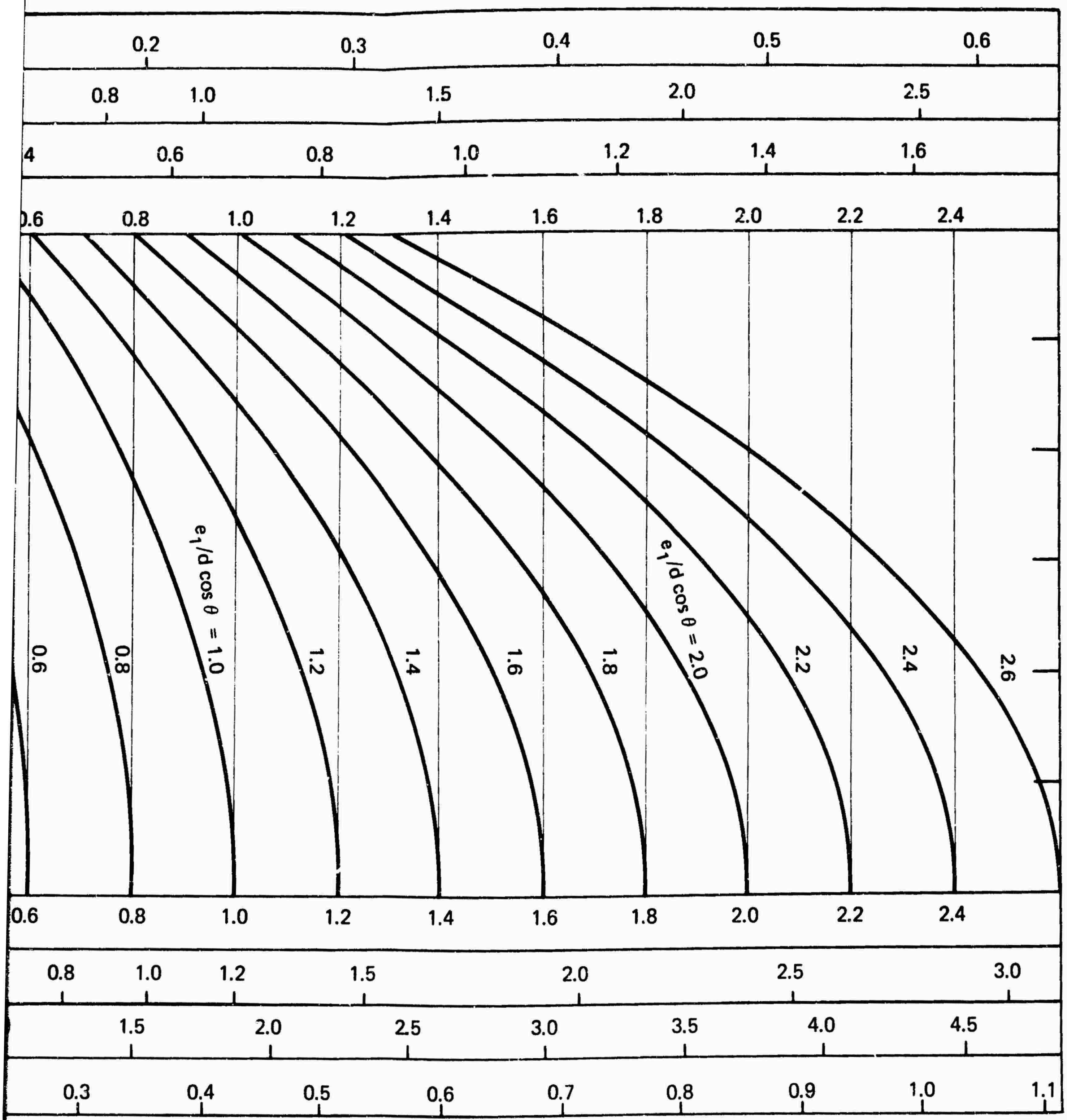


Material
UNDER ATTACK WITH CAL. .30 AP M2
Steel (in.) 0.1 0.2 0.3
Dowmetal (in.) 0.2 0.4 0.6 0.8 1.0 1.5
Dural (in.) 0.2 0.4 0.6 0.8
e1/d 0.2 0.4 0.6 0.8 1.0 1.2 1.4
50°
40°
30°
20°
10°
0.2
0.4
0.6
0.8
e1/d cos θ = 1.0
1.2
1.4
e1/d 0.2 0.4 0.6 0.8 1.0 1.2 1.4
Dural (in.) 0.2 0.4 0.6 0.8 1.0 1.2 1.5
Dowmetal (in.) 0.5 1.0 1.5 2.0 2.5
Steel (in.) 0.1 0.2 0.3 0.4 0.5 0.6
UNDER ATTACK WITH CAL. .50 AP M2

Fig
Var

A

UNDER ATTACK WITH CAL. .30 AP M2 PROJECTILES



UNDER ATTACK WITH CAL. .50 AP M2 PROJECTILES

Figure 1. Comparison of Actual Thicknesses of Materials of Various Density Needed to Yield Equivalent Values of e_1/d

B

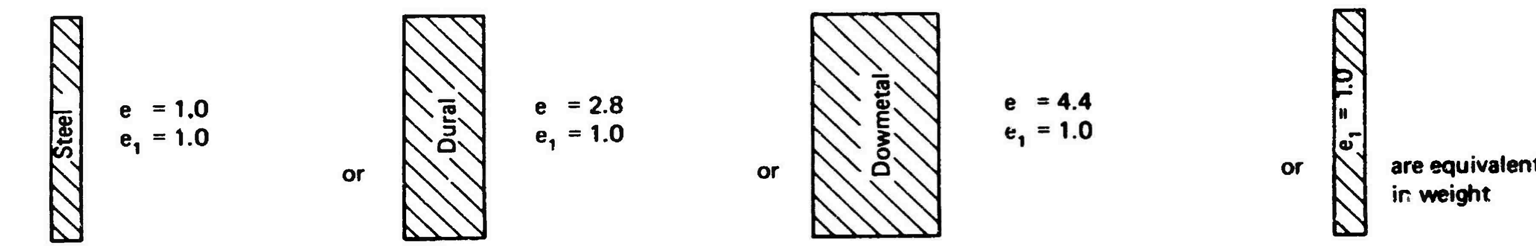


Figure 1A. Variation in Thickness of Materials Different in Density but Equivalent in Weight Per Unit Surface Area

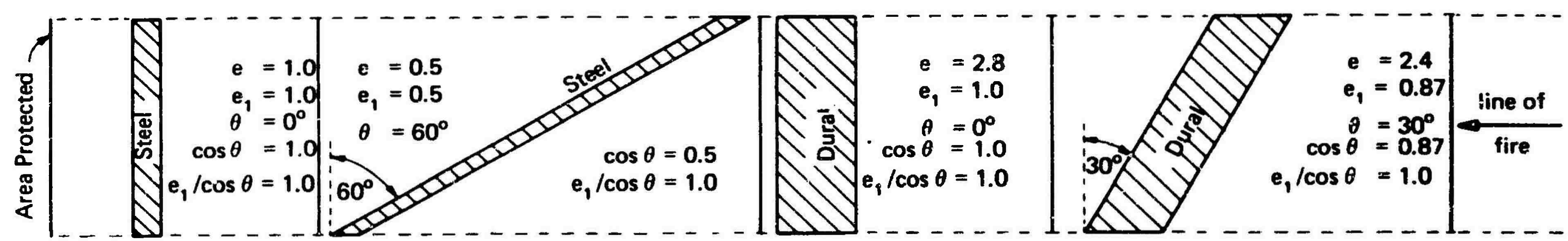


Figure 1B. Variation in Actual Thicknesses of Materials of Various Density and Obliquity of Installation but Equivalent in Weight Employed in Shielding a Unit Area Normal to the Direction of Projectile Incidence

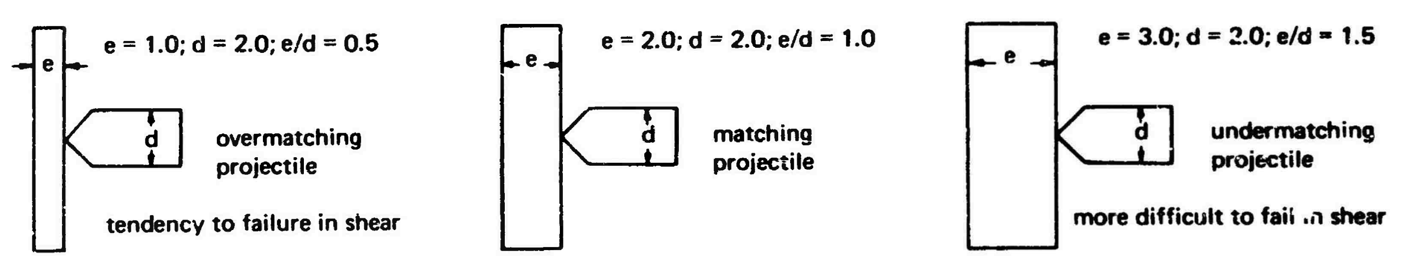
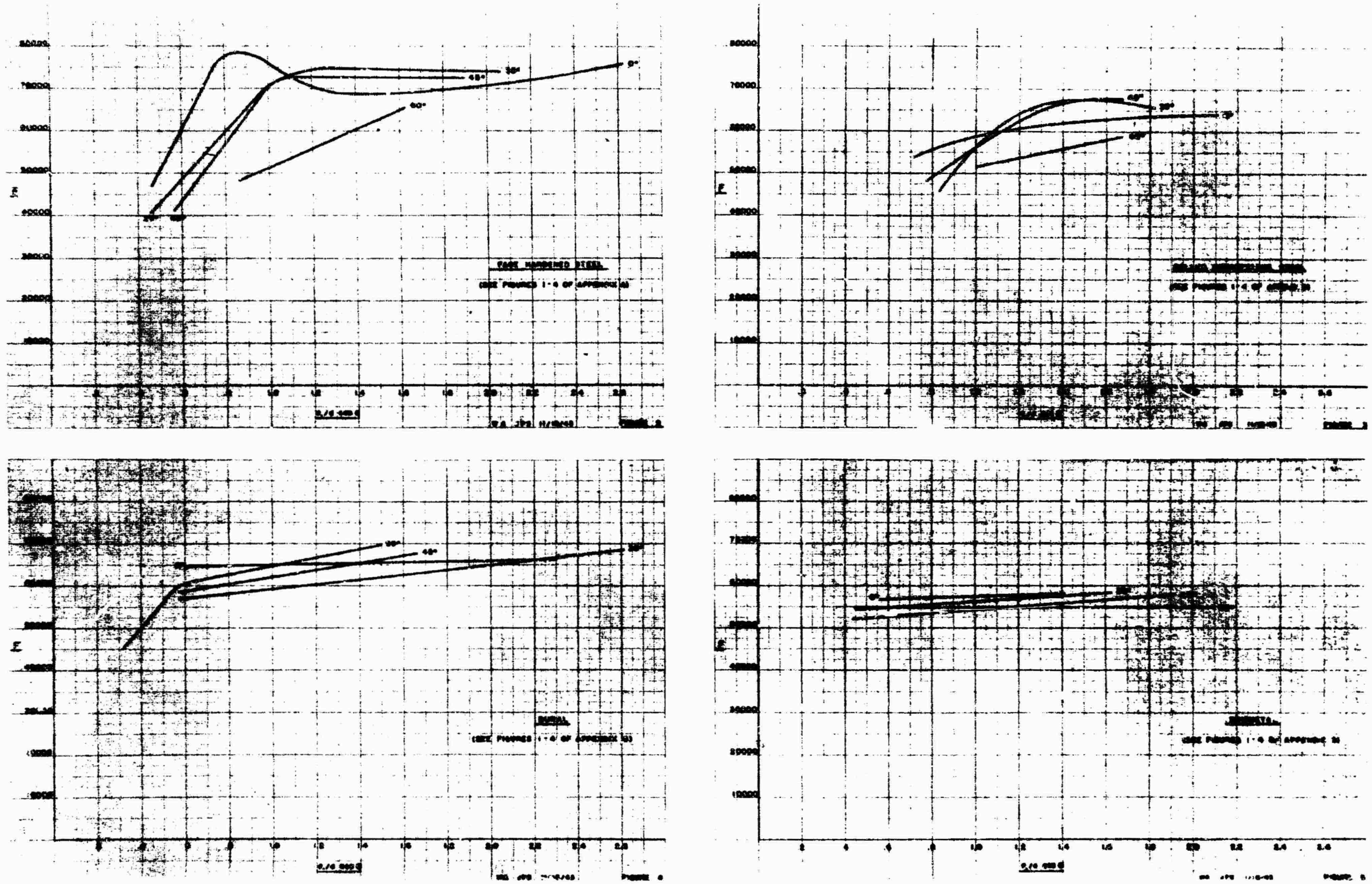
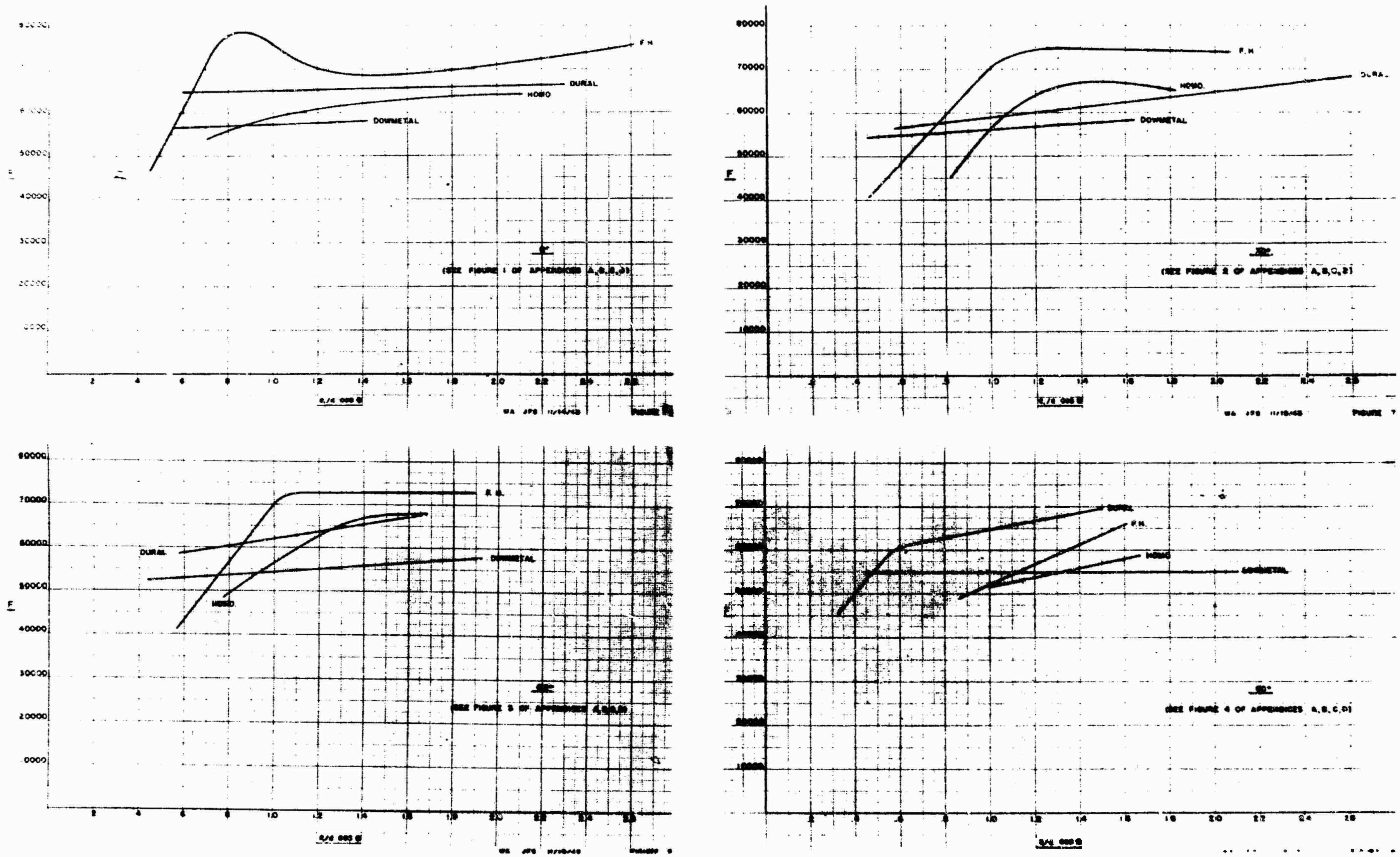


Figure 1C. Effect of Variation in Ratio of Plate Thickness to Projectile Diameter on Mechanism of Failure

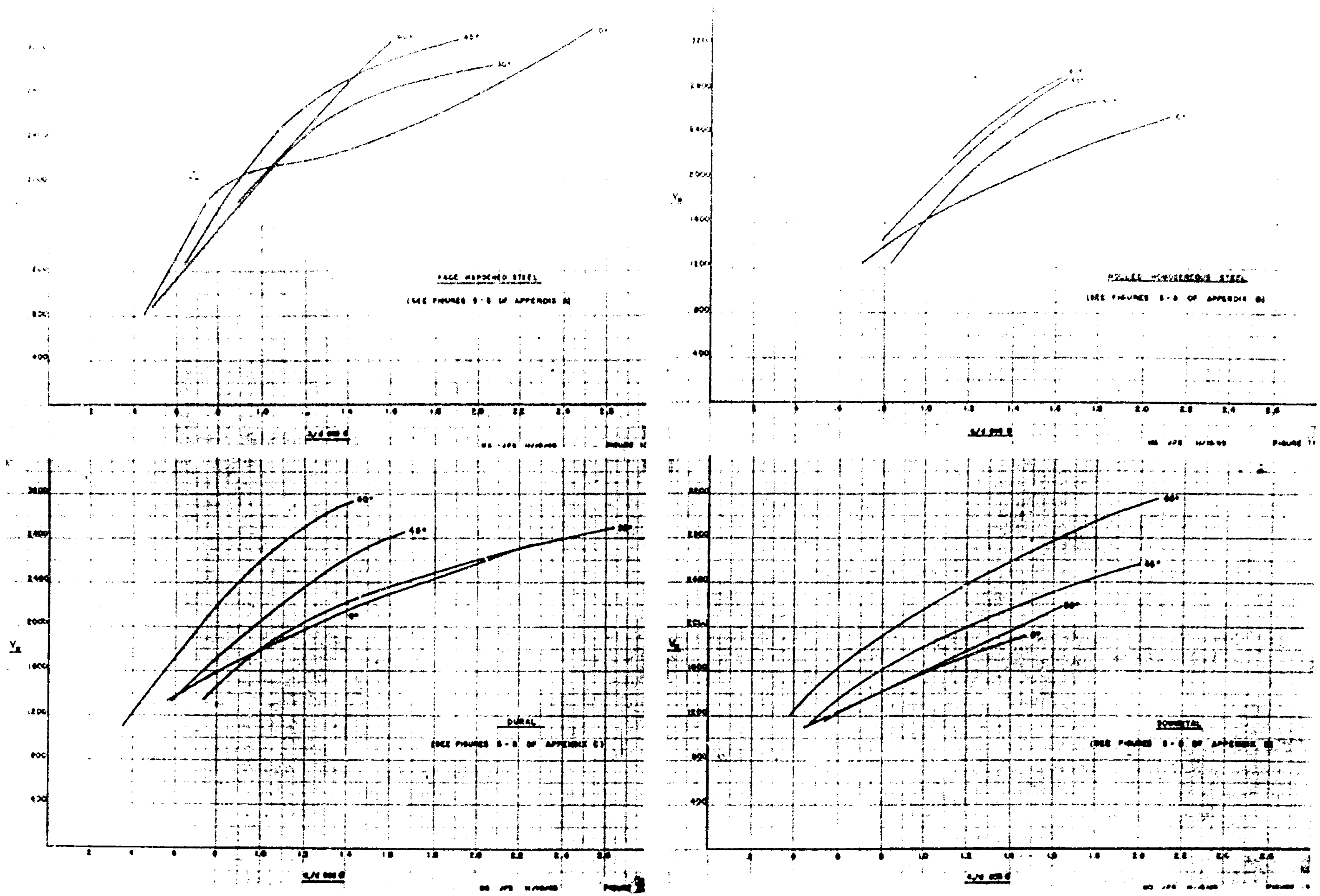


Figures 2 to 5. The Thompson Coefficient (F) as a Function of Obliquity (θ) and of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel of Equivalent Weight Per Unit Surface Area (e_1), to the Projectile Core Diameter (d), with Allowance for the Greater Amount of Obliquely Installed Material Necessary to Shield a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). Face-Hardened Steel, Rolled Homogeneous Steel, Duralumin, Dowmetal. WTN.639-5994

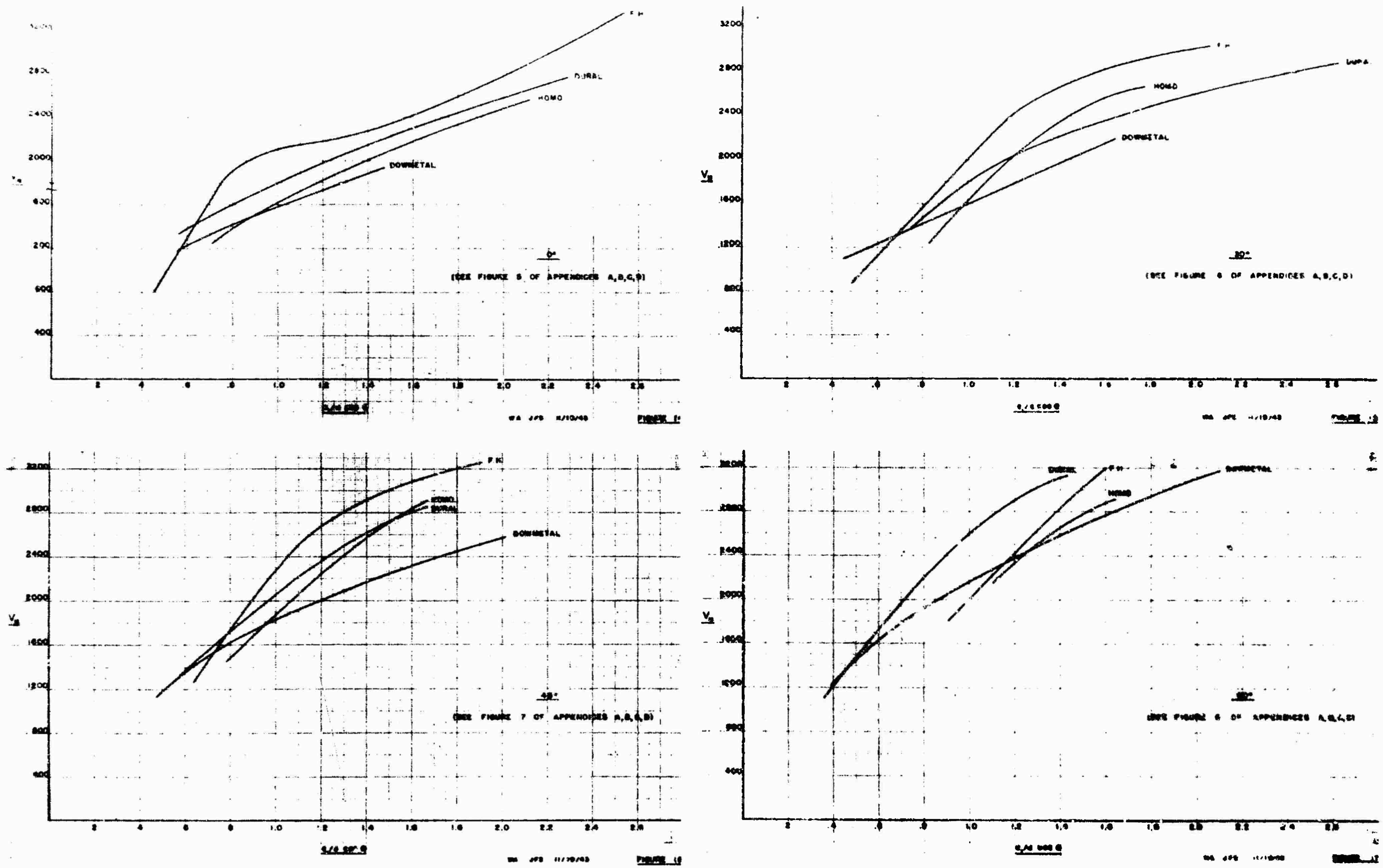


Figures 6 to 9. The Thompson Coefficient (F) as a Function of Plate Material and of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel of Equivalent Weight Per Unit Surface Area (e_1), to the Projectile Core Diameter (d), with Allowance for the Greater Amount of Obliquely Installed Material Necessary to Shield a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). 0°, 30°, 45°, 60°.

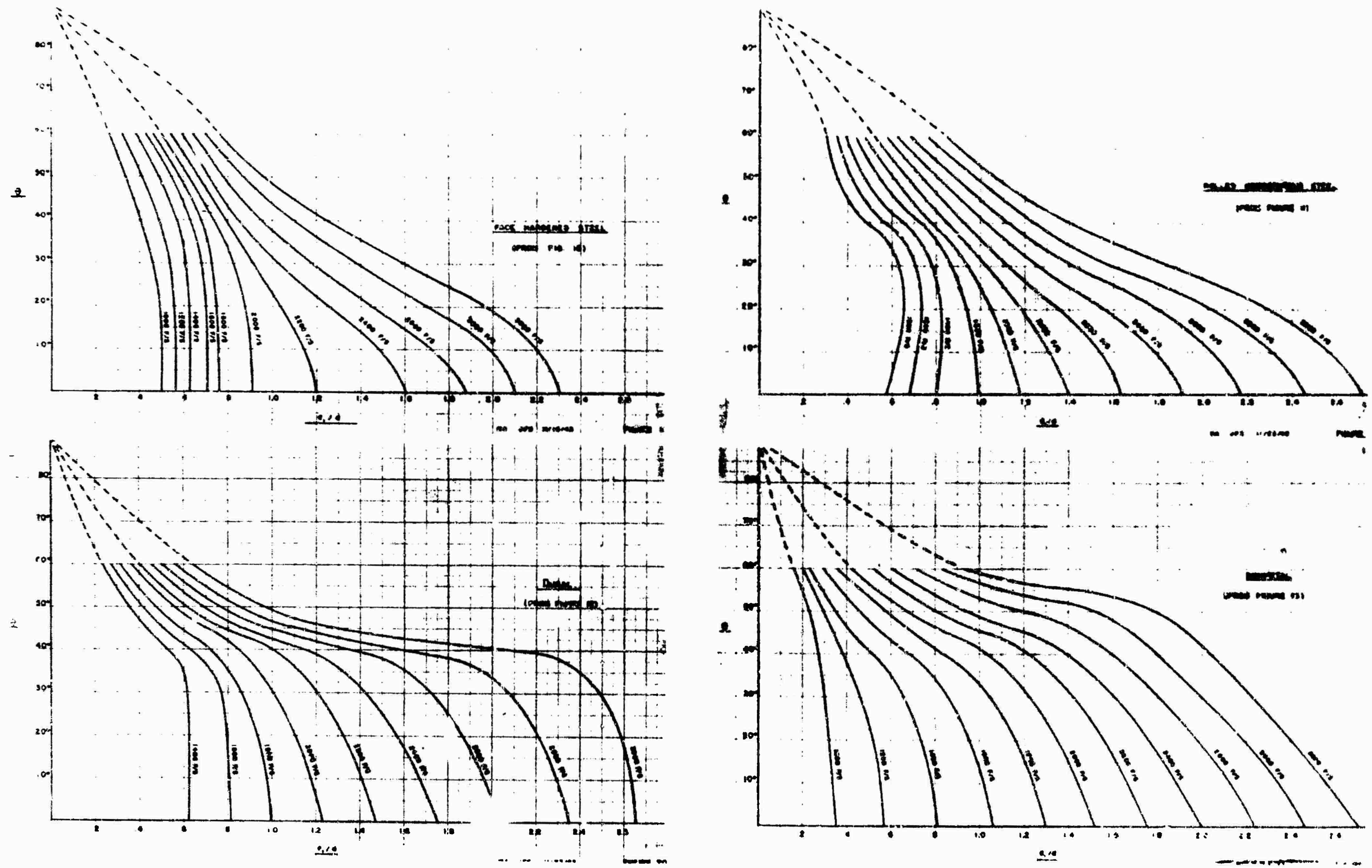
WTN.639-5998



Figures 10 to 13. Limit of Resistance to Perforation (V_N) as a Function of Obliquity (θ) and of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel of Equivalent Weight Per Unit Surface Area (e1), to the Projectile Core Diameter (d), with Allowance for the Greater Amount of Obliquely Installed Material Necessary to Protect a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). Face-Hardened Steel, Rolled Homogeneous Steel, Duralumin, Dowmetal. WTN-639-5997



Figures 14 to 17. Limit of Resistance to Perforation (V_N) as a Function of Plate Material and of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel and Equivalent Weight Per Unit Surface Area (e_1), to the Projectile Core Diameter (d), with Allowance for the Greater Amount of Obliquely Installed Material Necessary to Protect a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). 0°, 30°, 45°, 60°. WTN. 639-6002



Figures 18 to 21. Ratio of Plate Thickness (e), Corrected to Thickness of Steel of Equivalent Weight Per Unit Surface Area (e1), to Projectile Core Diameter (e1/d) Necessary to Resist Perforation by Cal..30 APM2 or Cal..50 APM2 Projectiles of Various Stricking Velocities at Various Degrees of Obliquity (θ). Face-Hardened Steel, Rolled Homogeneous Steel, Duralumin, Dowmetal. (Dowmetal Curves Also Valid for 20MM APM75 Projectile Perforation).
WTN.639-6000

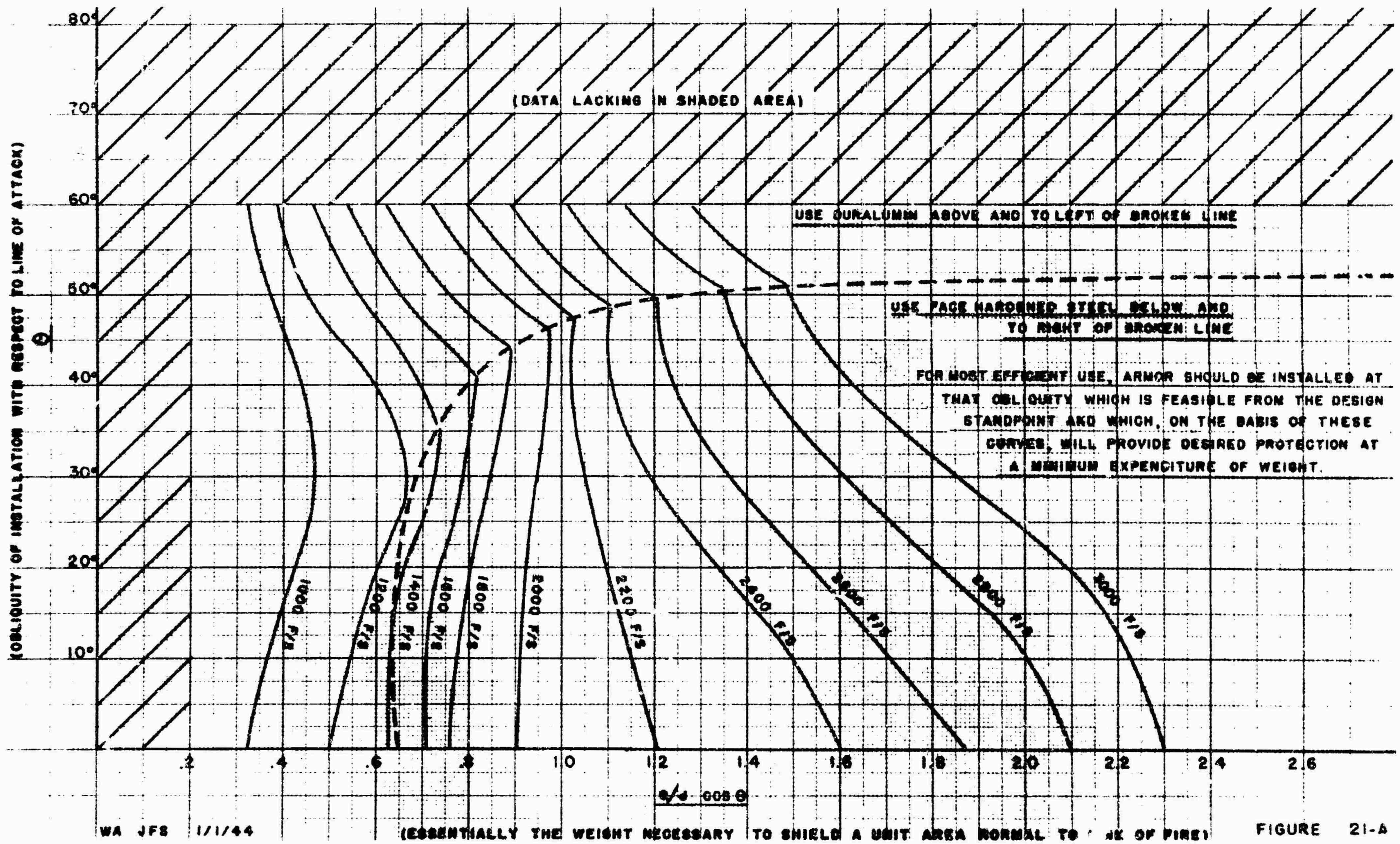
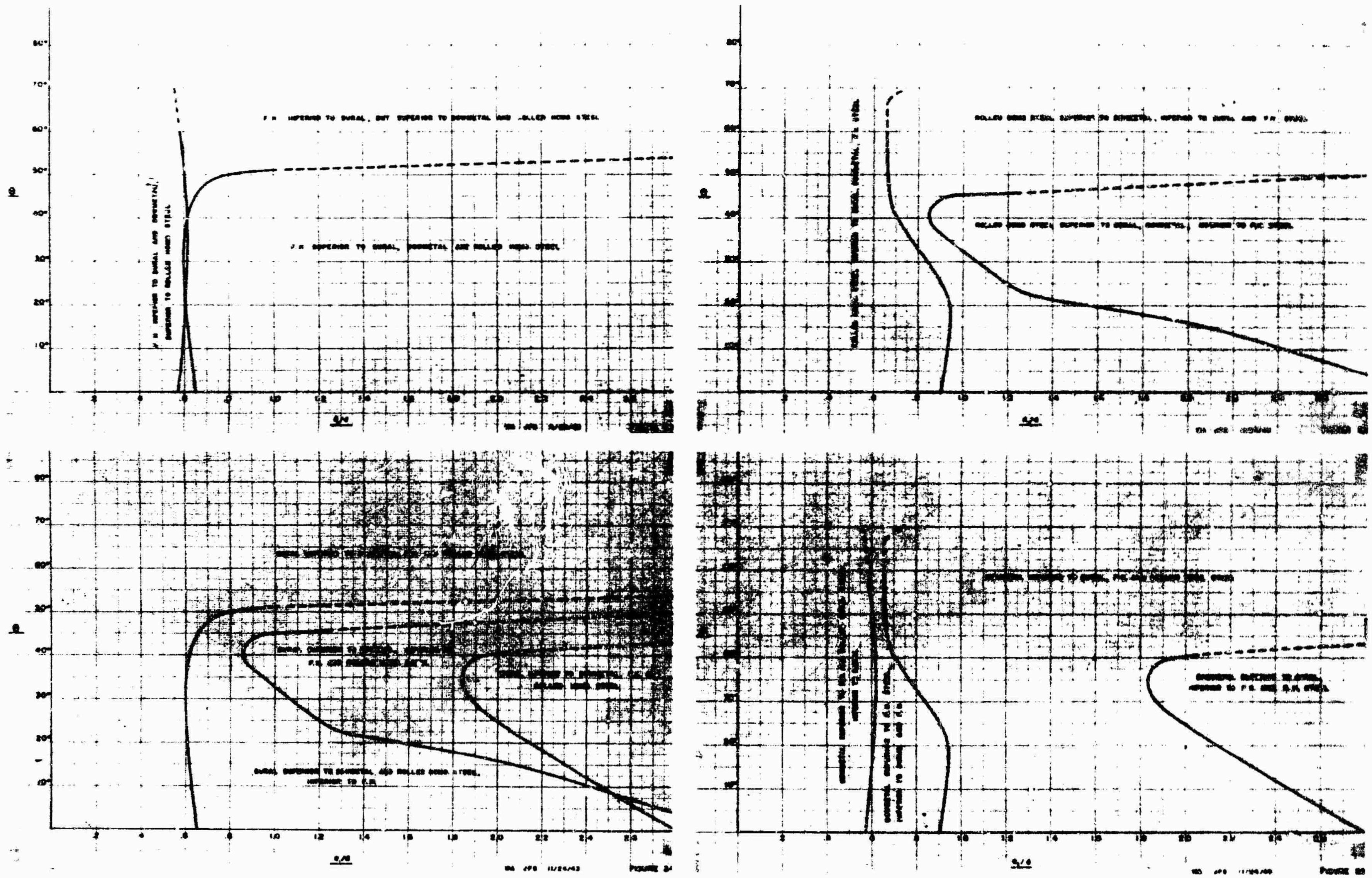


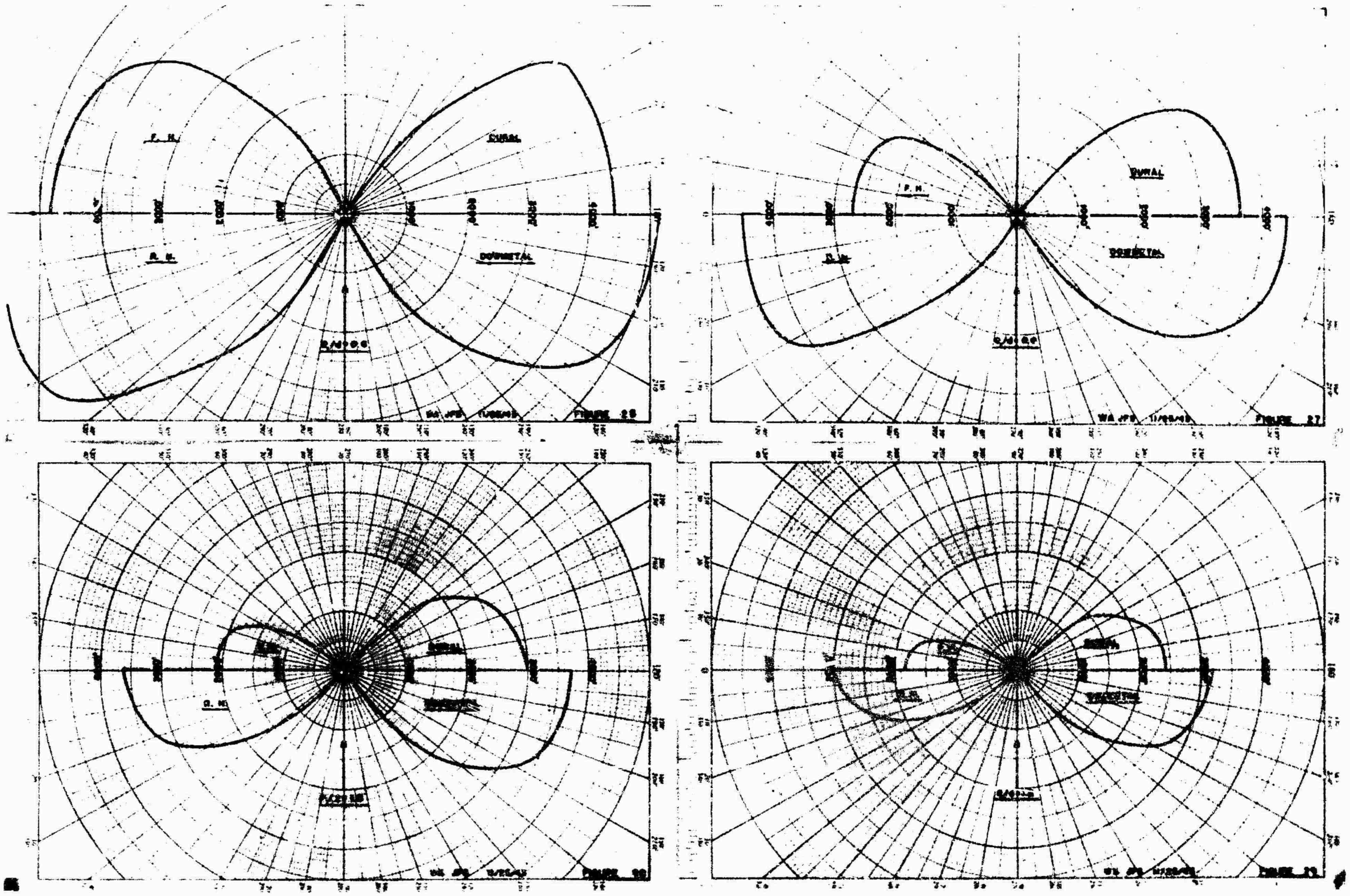
Figure 21A. An Empirical Basis for the Efficient Design (with Respect to Protection Afforded Per Unit Weight Employed) of Aircraft Armor. Expected to be Attacked with Cal. .30 AP M2 or Cal. .50 AP M2 Projectiles

WTN.639-6162



Figures 22 to 25. Circumstances, with Respect to Obliquity (θ) and Ratio of Plate Thickness, Corrected to Thickness of Steel of Equivalent Weight Per Unit Surface Area, to Projectile Core Diameter (e_1/d), Under Which Each Material is Superior and Inferior to Other Materials. Face-Hardened Steel. Rolled Homogeneous Steel, Duralumin, Dowmetal. (Based on Figures 18 to 21).

WTN.639-6001



Figures 26 to 29. Half-Areas of Vulnerability for Different Materials Under Different Ratios of Plate Thickness, Corrected to Thickness of Steel of Equivalent Weight Per Unit Surface Area, to the Projectile Core Diameter (e_1/d). e_1/d 0.6, 0.8, 1.0, 1.2. (Based on Cal..30 APM 2 and Cal..50 APM 2 Firings).

WTN.639-5995

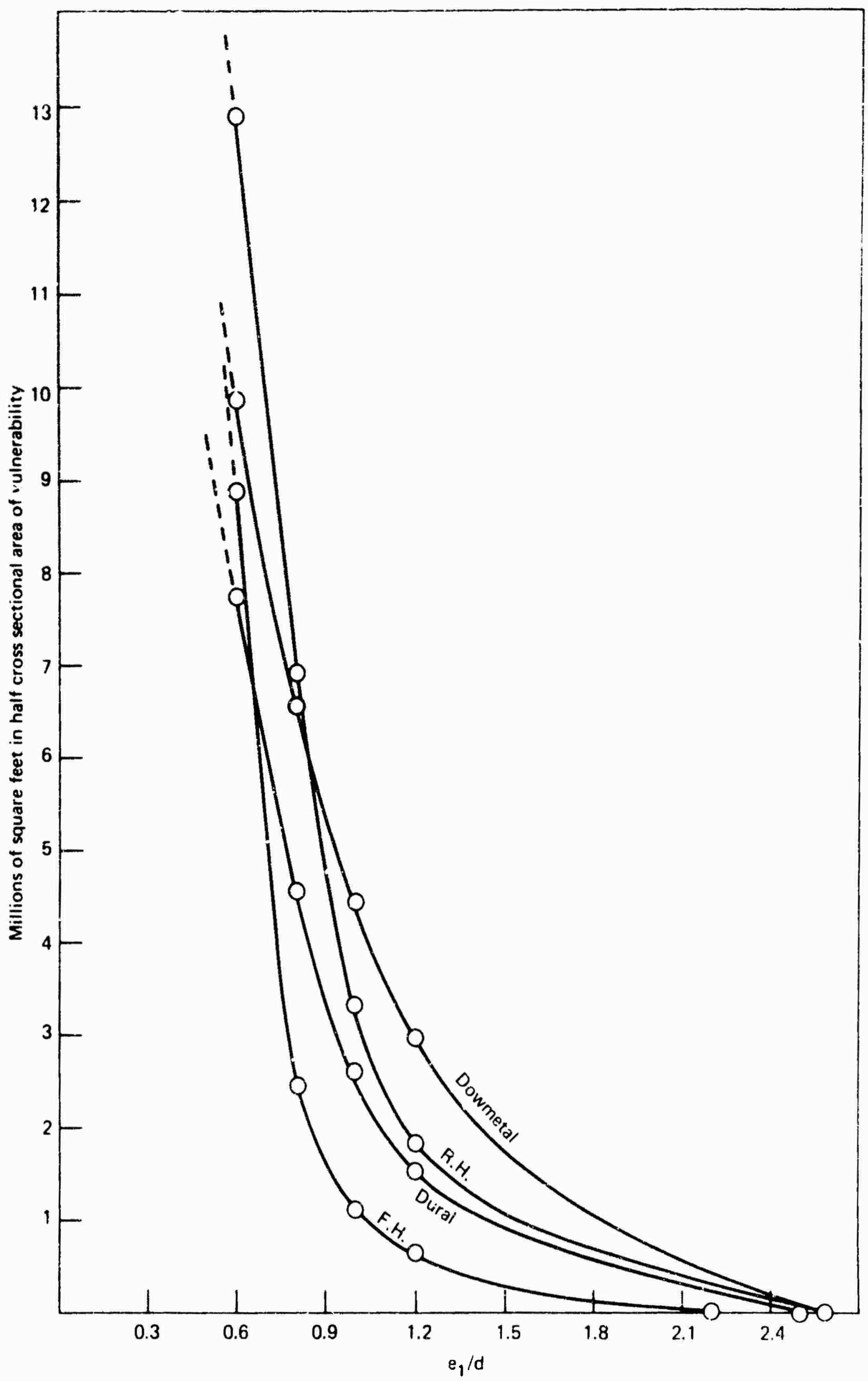


Figure 30. Effect of Change in Ratio of Plate Thickness, Adjusted for Density Variations to Projectile Caliber (e_1/d) On Vulnerability Areas for the Various Materials

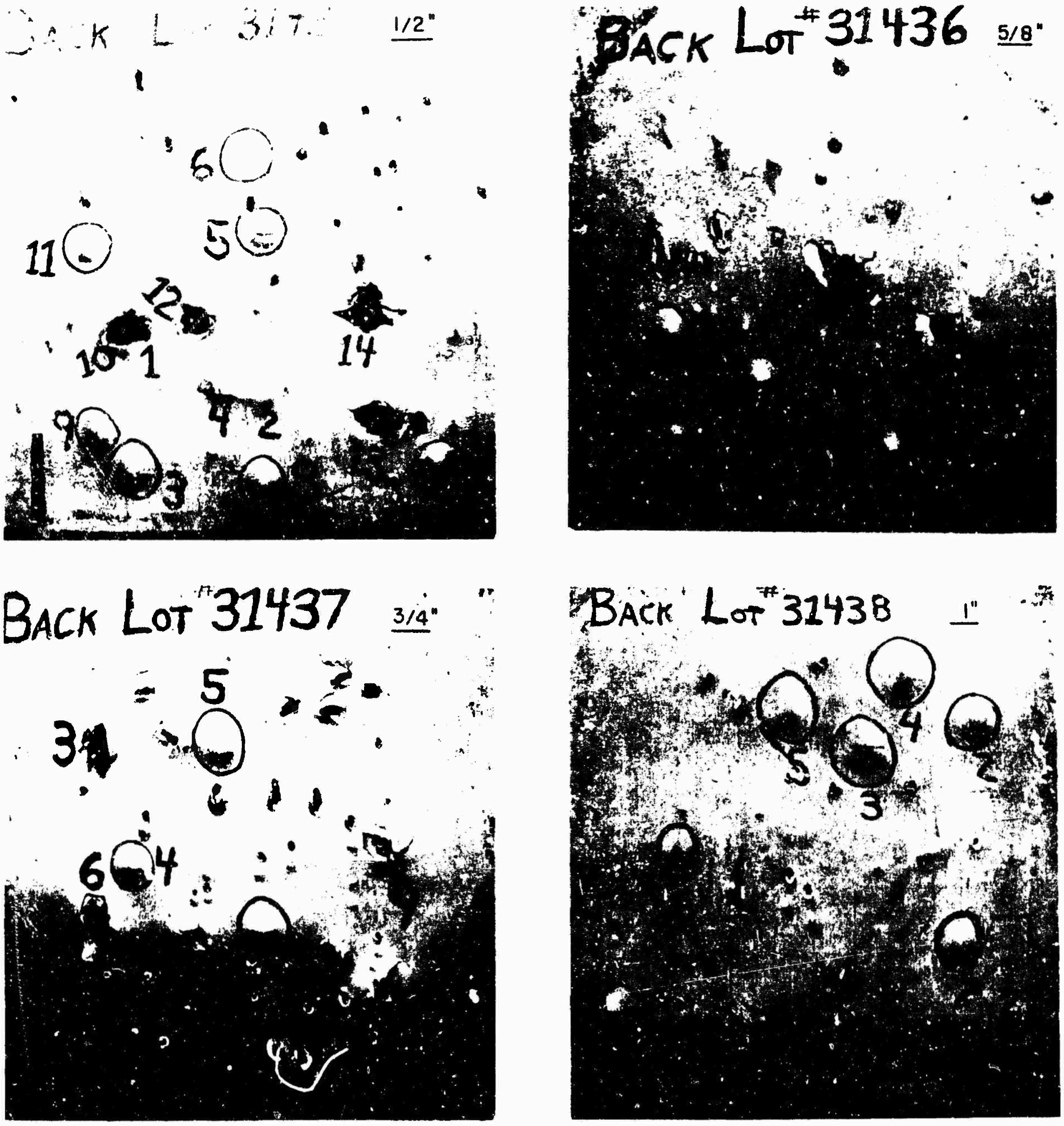


Figure 31. Typical Back Condition of 24 ST Duralumin Plate After Tests with Cal..30 APM2, Cal..50 APM2. (Yawed and Unyawed) and 20MM HE Projectiles

WTN.639-6004

APPENDIX A

APPENDIX A - TABLE I

Resistance to Perforation of Face-Hardened Armor of Various Thicknesses and at Various Obliquities under Impact of Cal. .30 AP M2 and Cal. .50 AP M2 Projectiles

Cal.	m/d^3	θ	V_L	e	e_1	e_1/d	$e_1/d \cos \theta$	F	Data Source
.50	1300	0°	1020	.186	.186	.435	.435	55,800	NRL-O-1745
.30	1300	0°	1055	.123	.123	.4805	.4805	54,900	NRL-O-1745
.30	1300	0°	995	.124	.124	.4845	.4845	51,600	NRL-O-1745
.30	1300	0°	1085	.125	.125	.488	.488	55,900	NRL-O-1745
.50	1275	0°	1392	.250	.250	.583	.583	65,100	APG AD-147
.50	1300	0°	1090	.254	.254	.594	.594	51,000	NRL-O-1745
.50	1300	0°	1245	.260	.260	.608	.608	57,600	NRL-O-1745
.50	1300	0°	1340	.263	.263	.614	.614	61,700	NRL-O-1745
.50	1300	0°	1350	.265	.265	.619	.619	61,900	NRL-O-1745
.50	1300	0°	1220	.275	.275	.642	.642	54,900	NRL-O-1745
.50	1275	0°	1374	.311	.311	.726	.726	56,700	APG A-7472
.30	1300	0°	1725	.186	.186	.727	.727	72,600	NRL-O-1745
.30	1300	0°	1825	.186	.186	.727	.727	77,300	NRL-O-1745
.50	1275	0°	1657	.315	.315	.735	.735	69,000	APG A-9485
.30	1300	0°	1930	.190	.190	.742	.742	80,200	NRL-O-1745
.50	1300	0°	1840	.332	.332	.776	.776	75,300	NRL-O-1745
.30	1300	0°	1885	.200	.200	.781	.781	76,900	NRL-O-1745
.50	1275	0°	2025	.368	.368	.859	.859	78,000	APG A-7472
.50	1275	0°	2101	.375	.375	.875	.875	80,200	W.A. 710/456
.50	1275	0°	2057	.375	.375	.875	.875	78,500	APG AD-148
.50	1275	0°	2105	.375	.375	.875	.875	80,400	APG AD-147
.50	1300	0°	1990	.376	.376	.879	.879	76,600	NRL-O-1745
.50	1300	0°	2090	.377	.377	.881	.881	80,300	NRL-O-1745
.50	1275	0°	1864	.383	.383	.894	.894	70,400	APG A-9485
.50	1300	0°	2040	.391	.391	.914	.914	77,000	NRL-O-1745
.30	1300	0°	2100	.254	.254	.992	.992	75,500	NRL-O-1745
.30	1300	0°	2200	.260	.260	1.016	1.016	78,200	NRL-O-1745
.30	1355	0°	2035	.250	.250	1.016	1.016	74,300	APG AD-52
.30	1355	0°	2171	.250	.250	1.016	1.016	79,300	APG AD-52
.30	1355	0°	2245	.250	.250	1.016	1.016	82,000	APG AD-52
.30	1355	0°	2213	.250	.250	1.016	1.016	80,800	APG AD-147
.30	1300	0°	2075	.263	.263	1.027	1.027	73,400	NRL-O-1745
.30	1300	0°	2125	.265	.265	1.035	1.035	75,400	NRL-O-1745
.30	1300	0°	2150	.265	.265	1.035	1.035	75,700	NRL-O-1745
.50	1275	0°	2080	.498	.498	1.162	1.162	68,900	APG A-7196
.50	1275	0°	2144	.500	.500	1.167	1.167	70,900	W.A. 710/456
.50	1275	0°	2155	.500	.500	1.167	1.167	71,200	APG A-7472
.50	1275	0°	2244	.500	.500	1.167	1.167	74,200	APG AD-52
.50	1275	0°	2111	.500	.500	1.167	1.167	69,800	APG AD-52
.50	1275	0°	2185	.500	.500	1.167	1.167	72,200	APG AD-148
.50	1275	0°	2185	.500	.500	1.167	1.167	72,200	APG AD-148
.50	1275	0°	2230	.500	.500	1.167	1.167	73,700	APG AD-147
.50	1300	0°	2155	.504	.504	1.177	1.177	71,700	NRL-O-1745
.50	1300	0°	2165	.504	.504	1.177	1.177	72,000	NRL-O-1745
.50	1275	0°	2201	.506	.506	1.181	1.181	72,300	APG-A-9486
.50	1300	0°	2165	.519	.519	1.212	1.212	70,900	NRL-O-1745

APPENDIX A - TABLE I
(Continued)

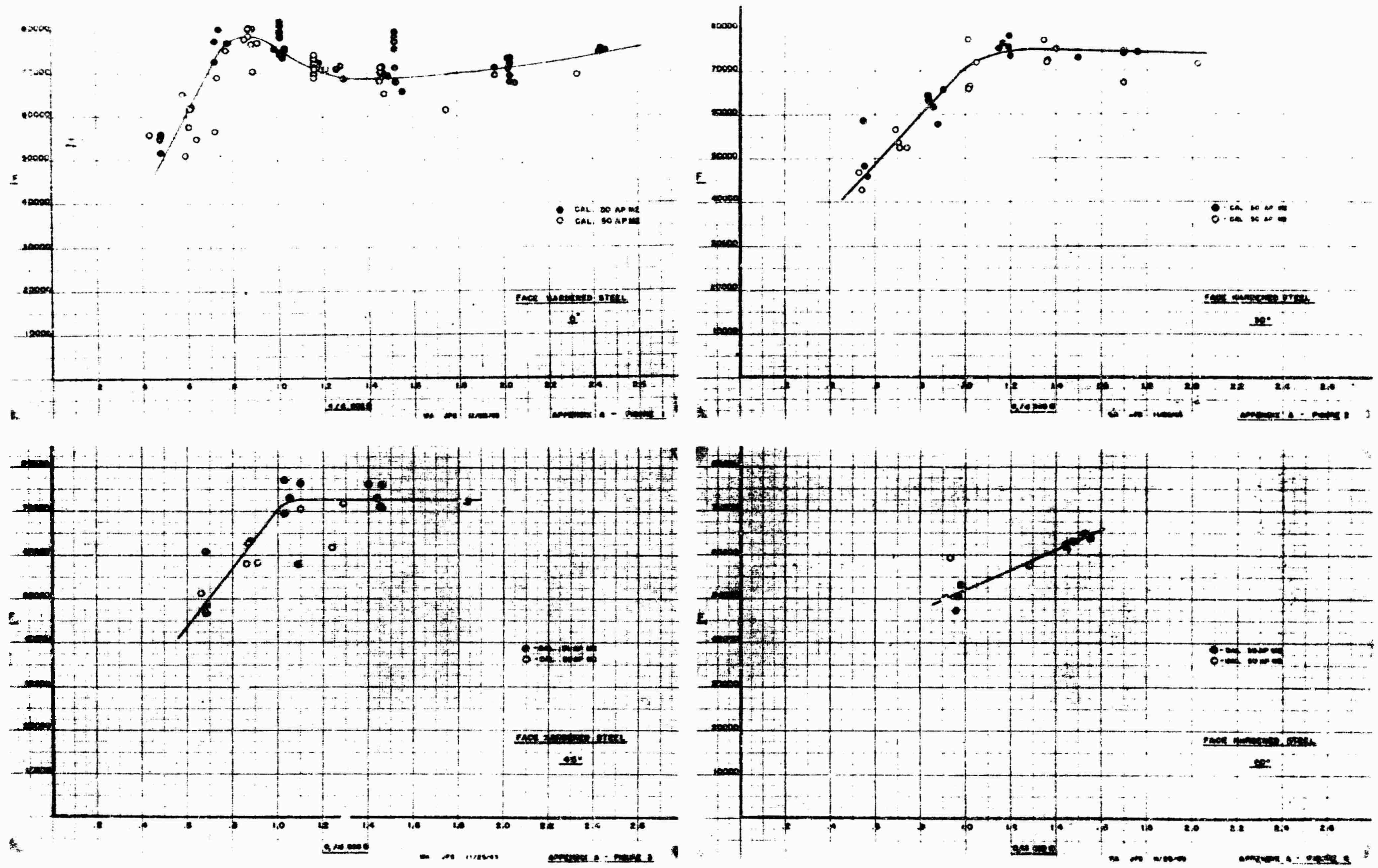
Cal.	m/d^3	θ	V_L	e	e_1	e_1/d	$e_1/d \cos\theta$	F	Data Source
.30	1355	0°	2165	.311	.311	1.264	1.264	70,900	APG A-7472
.30	1355	0°	2201	.315	.315	1.280	1.280	71,600	APG A-9485
.30	1300	0°	2165	.332	.332	1.297	1.297	68,600	NRL-0-1745
.50	1300	0°	2280	.621	.621	1.451	1.451	68,200	NRL-0-1745
.50	1300	0°	2290	.624	.624	1.458	1.458	68,400	NRL-0-1745
.50	1275	0°	2311	.625	.625	1.459	1.459	68,300	W.A. 710/456
.50	1275	0°	2408	.625	.625	1.459	1.459	71,200	APG AD-147
.50	1275	0°	2373	.625	.625	1.459	1.459	70,100	APG AD-147
.30	1300	0°	2415	.376	.376	1.469	1.469	71,300	NRL-0-1745
.50	1300	0°	2190	.630	.630	1.472	1.472	65,100	NRL-0-1745
.50	1300	0°	2370	.377	.377	1.472	1.472	69,800	NRL-0-1745
.30	1355	0°	2306	.368	.368	1.496	1.496	69,400	APG A-7472
.30	1355	0°	2591	.375	.375	1.524	1.524	77,200	APG AD-52
.30	1355	0°	2388	.375	.375	1.524	1.524	71,200	APG AD-52
.30	1355	0°	2525	.375	.375	1.524	1.524	75,300	APG AD-52
.30	1355	0°	2621	.375	.375	1.524	1.524	78,100	APG AD-148
.30	1355	0°	2659	.375	.375	1.524	1.524	79,300	APG AD-147
.30	1300	0°	2320	.391	.391	1.528	1.528	67,700	NRL-0-1745
.30	1355	0°	2228	.383	.383	1.557	1.557	65,700	APG A-9485
.50	1275	0°	2277	.75	.75	1.750	1.750	61,500	W.A. 710/456
.30	1300	0°	2720	.504	.504	1.968	1.968	69,400	NRL-0-1745
.30	1300	0°	2800	.504	.504	1.968	1.968	71,200	NRL-0-1745
.30	1355	0°	2830	.498	.498	2.024	2.024	73,200	APG A-7196
.30	1300	0°	2795	.519	.519	2.028	2.028	70,800	NRL-0-1745
.30	1355	0°	2628	.500	.500	2.033	2.033	67,800	APG A-7472
.30	1355	0°	2677	.500	.500	2.033	2.033	69,100	APG AD-148
.30	1355	0°	2793	.500	.500	2.033	2.033	72,100	APG AD-148
.30	1355	0°	2841	.500	.500	2.033	2.033	73,300	APG AD-147
.30	1555	0°	2634	.506	.506	2.056	2.056	67,600	APG A-9486
.50	1300	30°	1400	.254	.254	.594	.686	56,700	NRL-0-1745
.50	1300	30°	1340	.260	.260	.608	.702	53,700	NRL-0-1745
.50	1300	30°	1320	.263	.263	.614	.709	52,600	NRL-0-1745
.50	1300	30°	1310	.265	.265	.619	.715	52,000	NRL-0-1745
.50	1300	30°	1345	.275	.275	.642	.742	52,600	NRL-0-1745
.30	1300	30°	1735	.186	.186	.727	.839	63,600	NRL-0-1745
.30	1300	30°	1745	.186	.186	.727	.839	63,900	NRL-0-1745
.30	1300	30°	1700	.190	.190	.742	.857	61,600	NRL-0-1745
.30	1300	30°	1635	.197	.197	.769	.888	58,200	NRL-0-1745
.50	1300	30°	1750	.332	.332	.776	.896	62,000	NRL-0-1745
.30	1300	30°	1850	.200	.200	.781	.902	65,400	NRL-0-1745
.50	1275	30°	2331	.375	.375	.875	1.011	77,100	W.A. 710/456
.50	1300	30°	1970	.376	.376	.879	1.015	65,600	NRL-0-1745
.50	1300	30°	2000	.377	.377	.881	1.017	66,500	NRL-0-1745
.50	1300	30°	2190	.391	.391	.914	1.055	71,500	NRL-0-1745
.30	1300	30°	2390	.254	.254	.992	1.146	74,900	NRL-0-1745
.50	1275	0°	2978	1.00	1.00	2.334	2.334	69,600	W.A. 710/456
.30	1300	0°	3250	.621	.621	2.430	2.430	74,600	NRL-0-1745

APPENDIX A - TABLE I
(Continued)

Cal.	m/d^3	θ	V_L	e	e_1	e_1/d	$e_1/d \cos \theta$	F	Data Source
.50	1300	30°	1400	.254	.254	.594	.686	56,700	NRL-O-1745
.50	1300	30°	1340	.260	.260	.608	.702	53,700	NRL-O-1745
.50	1300	30°	1320	.263	.263	.614	.709	52,600	NRL-O-1745
.50	1300	30°	1310	.265	.265	.619	.715	52,000	NRL-O-1745
.50	1300	30°	1345	.275	.275	.642	.742	52,600	NRL-O-1745
.30	1300	30°	1735	.186	.186	.727	.839	63,600	NRL-O-1745
.30	1300	30°	1745	.186	.186	.727	.839	63,900	NRL-O-1745
.30	1300	30°	1700	.190	.190	.742	.857	61,600	NRL-O-1745
.30	1300	30°	1635	.197	.197	.769	.888	58,200	NRL-O-1745
.50	1300	30°	1750	.332	.332	.776	.896	62,000	NRL-O-1745
.30	1300	30°	1850	.200	.200	.781	.902	65,400	NRL-O-1745
.50	1275	30°	2331	.375	.375	875	1.011	77,100	W.A. 710/456
.50	1300	30°	1970	.376	.376	.879	1.015	65,600	NRL-O-1745
.50	1300	30°	2000	.377	.377	.881	1.017	66,500	NRL-O-1745
.50	1300	30°	2190	.391	.391	.914	1.055	71,500	NRL-O-1745
.30	1300	30°	2390	.254	.254	.992	1.146	74,900	NRL-O-1745
.30	1355	30°	2155	.250	.250	1.016	1.173	68,200	APG AD-52
.30	1355	30°	2516	.250	.250	1.016	1.173	79,600	APG AD-52
.30	1355	30°	2575	.250	.250	1.016	1.173	81,400	APG AD-52
.30	1300	30°	2450	.260	.260	1.016	1.173	75,900	NRL-O-1745
.30	1300	30°	2450	.263	.263	1.027	1.186	75,000	NRL-O-1745
.30	1300	30°	2400	.265	.265	1.035	1.195	73,100	NRL-O-1745
.30	1300	30°	2520	.265	.265	1.035	1.195	77,400	NRL-O-1745
.50	1275	30°	2725	.500	.500	1.167	1.347	78,000	APG AD-52
.50	1275	30°	2681	.500	.500	1.167	1.347	76,700	W.A. 710/456
.50	1275	30°	2352	.500	.500	1.167	1.347	67,300	APG AD-52
.50	1300	30°	2490	.504	.504	1.177	1.360	71,600	NRL-O-1745
.50	1300	30°	2500	.504	.504	1.177	1.360	71,900	NRL-O-1745
.50	1300	30°	2640	.519	.519	1.212	1.400	74,900	NRL-O-1745
.30	1300	30°	2655	.332	.332	1.297	1.498	72,800	NRL-O-1745
.30	1300	30°	2875	.376	.376	1.469	1.696	73,500	NRL-O-1745
.50	1300	30°	2590	.630	.630	1.472	1.700	66,700	NRL-O-1745
.30	1300	30°	2900	.377	.377	1.472	1.700	74,000	NRL-O-1745
.30	1300	30°	2925	.391	.391	1.528	1.764	73,900	NRL-O-1745
.50	1275	30°	3024	.750	.750	1.750	2.021	70,700	W.A. 710/456
.50	1275	40°	2308	.375	.375	.875	1.142	67,500	W.A. 710/456
.50	1275	40°	2968	.500	.500	1.167	1.523	75,200	W.A. 710/456
.50	1300	45°	1380	.200	.200	.467	.661	51,500	NRL-O-1745
.30	1300	45°	1660	.123	.123	.481	.680	61,000	NRL-O-1745
.30	1300	45°	1290	.124	.124	.485	.685	47,300	NRL-O-1745
.30	1300	45°	1325	.125	.125	.488	.691	48,500	NRL-O-1745
.50	1300	45°	1780	.260	.260	.608	.860	58,200	NRL-O-1745
.50	1300	45°	1935	.263	.263	.614	.869	63,000	NRL-O-1745
.50	1300	45°	1960	.265	.265	.619	.876	63,500	NRL-O-1745
.50	1300	45°	1840	.275	.275	.642	.909	58,500	NRL-O-1745
.30	1300	45°	2350	.186	.186	.727	1.027	69,700	NRL-O-1745
.30	1300	45°	2580	.186	.186	.727	1.027	77,200	NRL-O-1745

APPENDIX A - TABLE I
(Continued)

Cal.	m/d^3	θ	V_L	e	e_1	e_1/d	$e_1/d \cos\theta$	F	Data Source
.30	1300	45°	2490	.190	.190	.742	1.050	73,100	NRL-O-1745
.30	1300	45°	1995	.197	.197	.769	1.088	58,000	NRL-O-1745
.50	1300	45°	2440	.332	.332	.776	1.097	70,600	NRL-O-1745
.30	1300	45°	2650	.200	.200	.781	1.105	76,400	NRL-O-1745
.50	1275	45°	2721	.375	.375	.875	1.238	61,800	W.A. 710/456
.50	1300	45°	2710	.391	.391	.914	1.292	72,300	NRL-O-1745
.30	1300	45°	3010	.254	.254	.992	1.403	76,400	NRL-O-1745
.30	1300	45°	2900	.260	.260	1.016	1.436	72,800	NRL-O-1745
.30	1300	45°	2850	.263	.263	1.027	1.453	71,200	NRL-O-1745
.30	1300	45°	2840	.265	.265	1.035	1.464	70,600	NRL-O-1745
.30	1300	45°	3035	.265	.265	.765	1.035	1.464	76,100	NRL-O-1745
.30	1500	45°	3230	.332	.332	1.297	1.835	72,400	NRL-O-1745
.50	1300	60°	1890	.197	.197	.460	.920	50,200	NRL-O-1745
.50	1300	60°	2260	.200	.200	.467	.934	59,600	NRL-O-1745
.30	1300	60°	1835	.123	.123	.481	.961	47,700	NRL-O-1745
.30	1300	60°	1955	.124	.124	.485	.969	50,600	NRL-O-1745
.30	1300	60°	2065	.125	.125	.488	.977	53,300	NRL-O-1745
.50	1300	60°	2550	.275	.275	.642	1.285	57,400	NRL-O-1745
.30	1300	60°	2885	.186	.186	.727	1.453	61,100	NRL-O-1745
.30	1300	60°	2950	.186	.186	.727	1.453	61,900	NRL-O-1745
.30	1300	60°	3020	.190	.190	.742	1.484	62,700	NRL-O-1745
.30	1300	60°	3155	.197	.197	.769	1.538	64,900	NRL-O-1745
.50	1300	60°	3105	.200	.200	.781	1.562	63,400	NRL-O-1745



Appendix A - Figures 1 to 4. Face-Hardened Steel. The Thompson Coefficient (F) as a Function of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel of Equivalent Weight Per Unit Surface Area (e_1), to the Projectile Core Diameter (d), with Allowance for the Greater Amount of Obliquely Installed Material Necessary to Shield a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). 0°, 30°, 45°, 60°.

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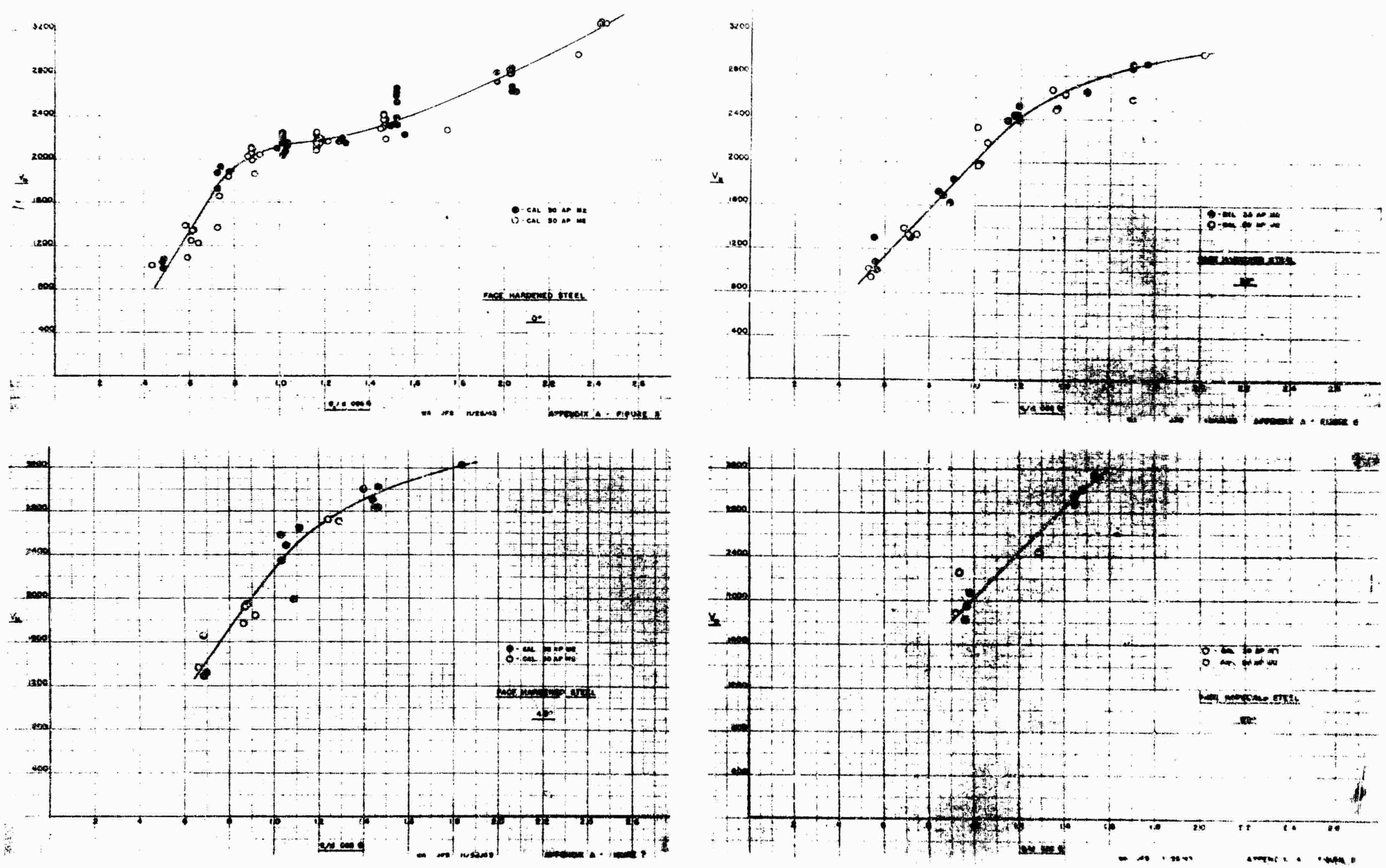


Appendix A - Figures 5 to 8. Face-Hardened Steel. Limit of Resistance to Perforation (V_N) as a Function of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel of Equivalent Weight Per Unit Surface Area (e_1), to the Projectile Core Diameter (d), with Allowance for the Greater Amount of Obliquely Installed Material Necessary to Protect a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). 0°, 30°, 45°, 60°.
WTN.639-5996

APPENDIX B

APPENDIX B - TABLE I

Resistance to Perforation of Rolled Homogeneous Steel of Various Thicknesses and at Various Obliquities under Impact of Cal. .30 AP M2 and Cal. .50 AP M2 Projectiles

Cal.	m/d^3	θ	V_L	e	e_1	e_1/d	$e_1/d \cos \theta$	F	Data Source
.50	1275	0°	1314	.319	.319	.744	.744	54,400	W.A. 710/493
.30	1355	0°	1327	.185	.185	.752	.752	56,300	W.A. 710/493
.50	1275	0°	1481	.376	.376	.877	.877	56,500	W.A. 710/493
.30	1355	0°	1639	.254	.254	1.033	1.033	59,400	W.A. 710/493
.50	1275	0°	1820	.503	.503	1.174	1.174	60,000	W.A. 710/493
.30	1535	0°	1861	.313	.313	1.272	1.272	60,700	W.A. 710/493
.50	1275	0°	2177	.625	.625	1.459	1.459	64,400	W.A. 710/493
.30	1535	0°	2082	.376	.376	1.528	1.528	62,000	W.A. 710/493
.50	1275	0°	2204	.750	.750	1.750	1.750	59,500	W.A. 710/493
.30	1535	0°	2525	.503	.503	2.045	2.045	65,000	W.A. 710/493
.50	1275	0°	2518	.878	.878	2.049	2.049	62,800	W.A. 710/493
.50	1275	10°	2291	.75	.75	1.750	1.777	60,900	W.A. 710/456
.50	1275	10°	2703	1.00	1.00	2.334	2.370	62,200	W.A. 710/456
.50	1275	20°	1906	.375	.375	.875	.931	68,400	W.A. 710/456
.50	1275	20°	2136	.5	.5	1.167	1.242	66,300	W.A. 710/456
.50	1275	20°	2333	.625	.625	1.459	1.552	64,800	W.A. 710/456
.50	1275	20°	2614	.75	.75	1.750	1.863	66,300	W.A. 710/456
.50	1275	20°	2848	1.00	1.00	2.334	2.484	62,600	W.A. 710/456
.50	1275	30°	1340	.320	.320	.747	.863	47,900	W.A. 710/493
.30	1355	30°	1309	.185	.185	.752	.868	48,100	W.A. 710/493
.50	1275	30°	1731	.375	.375	.875	1.010	57,200	W.A. 710/493
.30	1355	30°	2001	.254	.254	1.033	1.193	62,800	W.A. 710/493
.50	1275	30°	2371	.503	.503	1.174	1.356	67,700	W.A. 710/493
.30	1355	30°	2375	.312	.312	1.268	1.464	67,200	W.A. 710/493
.30	1355	30°	2545	.376	.376	1.528	1.764	65,600	W.A. 710/493
.50	1275	40°	2482	.375	.375	.875	1.142	72,600	W.A. 710/456
.50	1275	40°	2708	.5	.5	1.167	1.523	68,600	W.A. 710/456
.50	1275	45°	1560	.245	.245	.572	.809	52,100	W.A. R-2187
.50	1275	45°	1426	.256	.256	.597	.844	46,600	W.A. R-2186
.50	1275	45°	2275	.344	.344	.803	1.135	64,100	W.A. R-2185
.50	1275	45°	2075	.375	.375	.875	1.237	56,000	W.A. R-2184
.50	1275	45°	2672	.375	.375	.875	1.237	72,100	W.A. 710/456
.30	1355	45°	2655	.245	.245	.996	1.408	69,300	W.A. R-2187
.30	1355	45°	2550	.256	.256	1.041	1.472	65,100	W.A. R-2186
.50	1275	45°	2825	.490	.490	1.144	1.618	66,700	W.A. R-2183
.50	1275	45°	2845	.490	.490	1.144	1.618	67,200	W.A. R-2182
.50	1275	60°	2165	.245	.245	.572	1.144	51,100	W.A. R-2187
.50	1275	60°	2378	.256	.256	.597	1.194	54,900	W.A. R-2186
.50	1275	60°	2864	.344	.344	.803	1.606	57,100	W.A. R-2185

APPENDIX B - Ballistic Data Sheet No. 1

Rolled Homogeneous Plate 668-0, .245" x 28 1/2" x 36"
BHN 321-343 Reference WA-R2187

Cal. .30 AP M2 Firings:

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
45°	27	2057	PP-SB
45°	28	2492	PP-MB
45°	29	2760	Hit Rd. #20 - Disregard
45°	30	2760	CP-PTP Exit hole 1/4" x 5/16"
45°	31	2660[a,n]	CP-PTP Exit hole 7/16" x 5/16"
45°	32	2585	PP-MB
45°	33	2650[a,n]	PP-MB

[a] Army Ballistic Limit 2655 f/s
[n] Navy Ballistic Limit 2655 f/s

Cal. .50 AP M2 Firings:

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
45°	21	1895	CP-PTP Exit hole 1-1/8" x 1/2"
45°	22	1780	CP-PTP Exit hole 11/13" x 1/2"
45°	23	1785	CP-PTP Exit hole 3/8" x 5/8"
45°	24	1610	CP-PTP Exit hole 3/4" x 1/2"
45°	25	1540[a,n]	PP-Pun S
45°	26	1580[a,n]	CP-PTP Exit hole 1/2" x 3/8"

[a] Army Ballistic Limit 1560 f/s
[n] Navy Ballistic Limit 1560 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
60°	15	2390	CP-PTP Exit hole 1/2" x 13/16"
60°	16	2365	CP-PTP Exit hole 5/8" x 5/8"
60°	17	2285	CP-PTP Exit hole 1/2" x 3/4"
60°	18	2155[a,n]	CP-CIP
60°	19	2175[n]	CP-PTP Exit hole 1/2" x 13/16"
60°	20	2105[a]	PP-LB

[a] Army Ballistic Limit 2130 f/s
[n] Navy Ballistic Limit 2165 f/s

APPENDIX B - Ballistic Data Sheet No. 2

Rolled Homogeneous Plate 670-0, .256" x 28-1/2" x 36"
BHN 341-363 Reference WA-R2186

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings:			
45°	19	2597	CP-PTP Exit hole 5/16" x 3/8"
45°	20	2550[a,n]	CP-PTP Exit hole 7/16" x 5/16"
45°	21	2405	PP-SB
45°	22	2462	PP-MB
45°	23	2550[a,n]	PP-MB
		[a]Army Ballistic Limit 2550 f/s	
		[n]Navy Ballistic Limit 2550 f/s	
Cal. .50 AP M2 Firings:			
45°	24	1553	CP-PTP Exit hole 3/16" x 3/8"
45°	25	1495	CP-PTP Exit hole 7/16" x 1/2"
45°	26	1445[a,n]	CP-PTP Exit hole 1/2" x 1/2"
45°	27	1445	Hit Rd. #18 - Disregard
45°	28	1407[a,n]	PP-Pun S
		[a]Army Ballistic Limit 1426 f/s	
		[n]Navy Ballistic Limit 1426 f/s	
60°	13	1875	PP-SB
60°	14	2219	PP-Pun S
60°	15	2367[a,n]	PP-LB
60°	16	2500	CP-PTP Exit hole 5/8" x 1/2"
60°	17	lost	CP-PTP Exit hole 1/2" x 3/4"
60°	18	2388[a,n]	CP-PTP Exit hole 1/2" x 3/4"
		[a]Army Ballistic Limit 2378 f/s	
		[n]Navy Ballistic Limit 2378 f/s	

APPENDIX B - **Ballistic Data Sheet No. 3**

Rolled Homogeneous Plate 670-1, .344" x 28-1/2" x 36"
BHN 302-321 Reference WA-R2185

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 Firings:			
45°	12	2239^{n}	CP-FPTP
45°	13	2275^{n}	CP-PTP Exit hole 1/2" x 7/16"
45°	14	2065	CP-CIP-BD
45°	15	1925	CP-FPTP
45°	16	1826	CP-FPTP
45°	17	1720^{a}	CP-FPTP
45°	18	1680^{a}	PP-MB

[a]Army Ballistic Limit 1700 f/s
[n]Navy Ballistic Limit 2275 f/s

APPENDIX B - Ballistic Data Sheet No. 4

Rolled Homogeneous Plate 668-1, .375" x 28-1/2" x 36"
BHN363 Reference WA-R2184

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 Firings:			
45°	14	2179	CP-FPTP
45°	15	lost	CP-PTP Exit hole 1/2" x 7/16"
45°	16	2229	CP-PTP Exit hole 13/16" x 7/16"
45°	17	2035	PP-Pun S
45°	18	2002	PP-MB
45°	19	2175	CP-FPTP
45°	20	$2100^{a,n}$	CP-PTP Exit hole 3/4" x 7/16"
45°	21	$2050^{a,n}$	PP-MB

[a]Army Ballistic Limit - 2075 f/s
[n]Navy Ballistic Limit - 2075 f/s

APPENDIX B - Ballistic Data Sheet No. 5

Rolled Homogeneous Plate 670-2, .490" x 28-1/2" x 36"
BHN 341-363 Reference WA-R2182

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 Firings:			
45°	9	2830[a,n]	PP-MB
45°	10	2875	CP-PTP Exit hole 9/16" x 1/2"
45°	11	2860[a,n]	CP-PTP Exit hole 5/8" x 1/2"

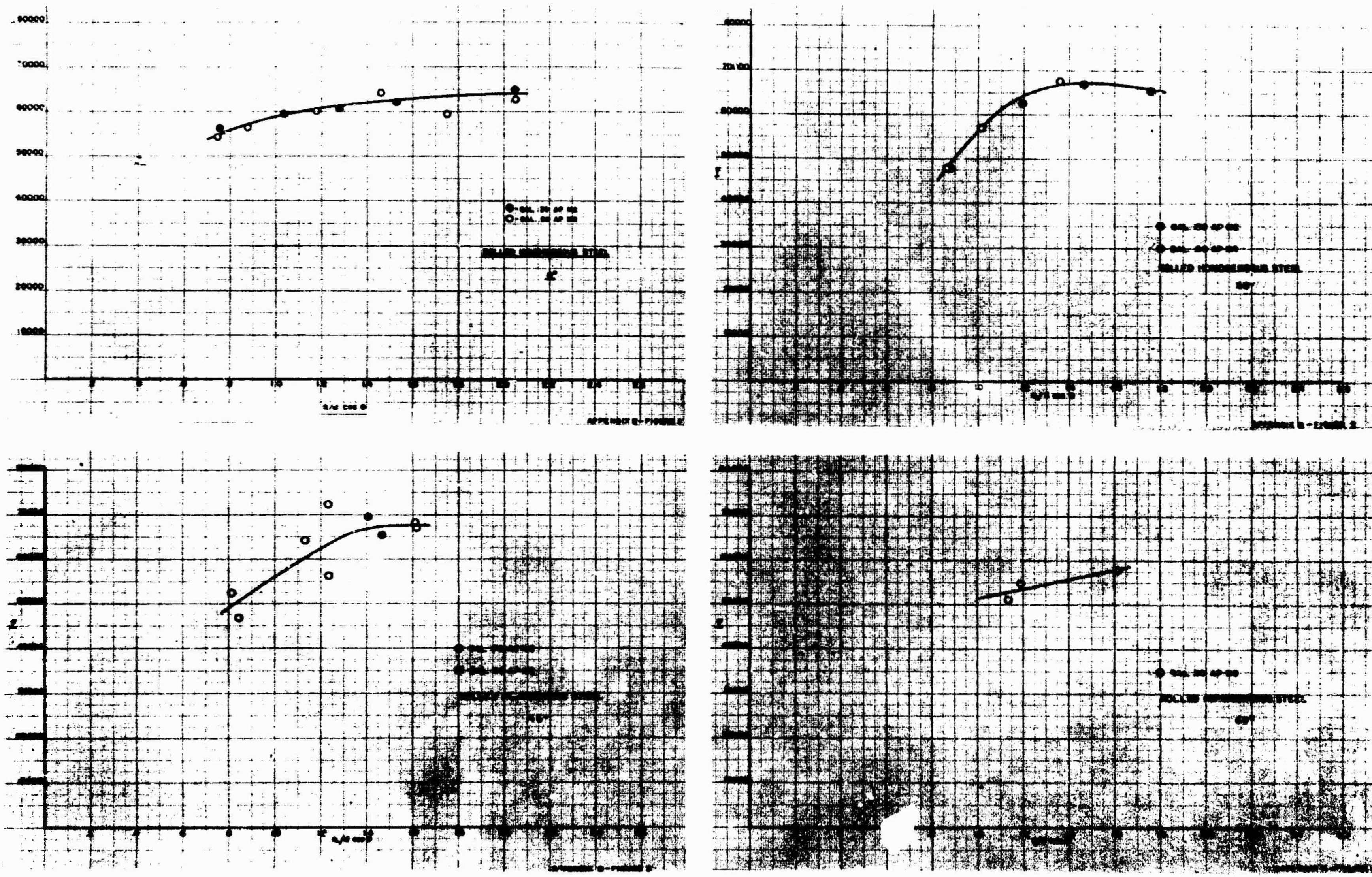
[a]Army Ballistic Limit 2845 f/s
[b]Navy Ballistic Limit 2845 f/s

APPENDIX B - Ballistic Data Sheet No. 6

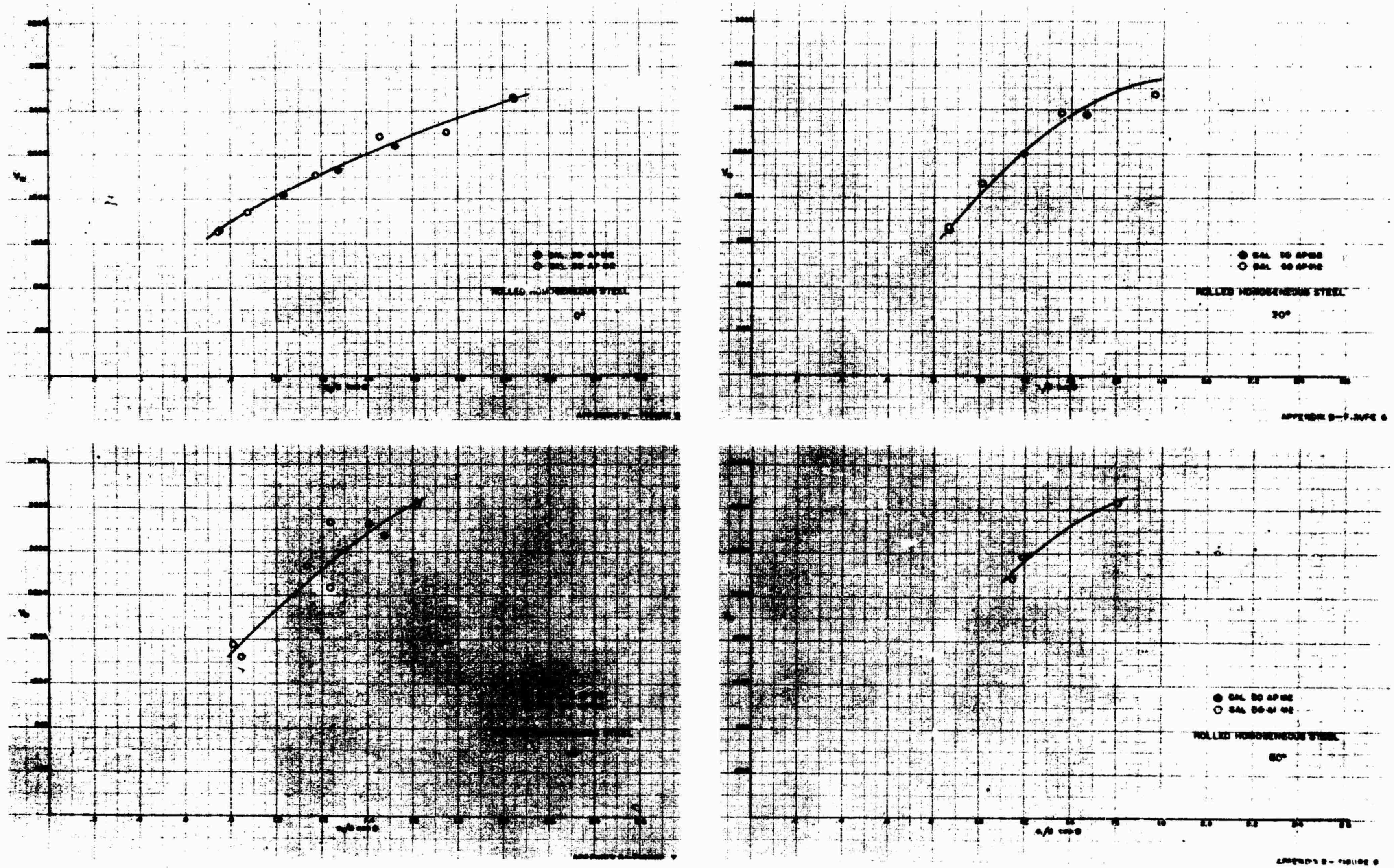
Rolled Homogeneous Plate 668-2, .490" x 28-1/2" x 36"
BHN 331-341 Reference WA-R2183

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 Firings:			
45°	12	2370	PP-SB
45°	13	2420	PP-SB
45°	14	2625	PP-SB
45°	15	2850[n]	CP-PTP Exit hole 5/8" x 5/8"
45°	16	2780[a]	CP-FPTP
45°	17	2800[n]	PP-Pun S
45°	18	2730[a]	PP-MB

[a]Army Ballistic Limit 2755 f/s
[b]Navy Ballistic Limit 2825 f/s



Appendix B - Figures 1 to 4. Rolled Homogeneous Steel. The Thompson Coefficient (F) as a Function of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel of Equivalent Weight Per Unit Surface Area (e_1), to the Projectile Core Diameter (d), With Allowance for the Greater Amount of Obliquely Installed Material Necessary to Protect a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). 0°, 30°, 45°, 60°.
WTN639-6036



Appendix B - Figures 5 to 8. Rolled Homogeneous Steel. Limit of Resistance to Perforation (V_N) as a Function of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel of Equivalent Weight Per Unit. Surface Area (e_1), to the Projectile Core Diameter (d), with Allowance for the Greater Amount of Obliquely Installed Material Necessary to Protect a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). 0°, 30°, 45°, 60°.

WTN.639-6035

APPENDIX C

APPENDIX C - TABLE I

Resistance to Perforation of 24ST and 14ST Dural of Various Thicknesses and at Various Obliquities under Impact of Cal. .30 AP M2 and Cal. .50 AP M2 Projectiles

Cal.	m/d^3	θ	V_N	e	e_1	e_1/d	$e_1/d \cos\theta$	F	Data Source
.50	1300	0°	1430	.757	.270	.632	.632	64,800	NRL-O-1745
.30	1355	0°	1497	.500	.178	.724	.724	64,800	APG-AD-69
.30	1355	0°	1532	.500	.178	.724	.724	66,300	APG-AD-69
.30	1300	0°	1500	.525	.188	.732	.732	63,200	NRL-O-1745
.50	1275	0°	1606	1.000	.356	.831	.831	62,900	APG-AD-69
.30	1355	0°	1865	.750	.267	1.085	1.085	65,900	APG-AD-69
.30	1300	0°	1950	.866	.309	1.208	1.208	64,000	NRL-O-1745
.50	1300	0°	2035	1.528	.546	1.275	1.275	65,000	NRL-O-1745
.50	1300	0°	2075	1.610	.575	1.344	1.344	64,500	NRL-O-1745
.30	1355	0°	2126	1.000	.356	1.447	1.447	65,100	APG-AD-69
.30	1300	0°	2775	1.610	.575	2.247	2.247	66,800	NRL-O-1745
.50	1300	30°	1490	.760	.271	.634	.732	58,600	NRL-O-1745
.50	1300	30°	1500	.866	.309	.722	.834	55,200	NRL-O-1745
.30	1355	30°	1521	.500	.178	.724	.836	57,000	APG-AD-69
.30	1355	30°	1527	.500	.178	.724	.836	57,200	APG-AD-69
.30	1300	30°	1540	.525	.188	.732	.846	56,200	NRL-O-1745
.50	1275	30°	1687	1.000	.356	.831	.959	57,200	APG-AD-69
.30	1355	30°	2085	.750	.267	1.085	1.253	63,800	APG-AD-69
.30	1300	30°	2250	.866	.309	1.208	1.395	63,900	NRL-O-1745
.50	1300	30°	2280	1.610	.575	1.344	1.552	61,400	NRL-O-1745
.30	1355	30°	2421	1.000	.356	1.447	1.671	64,200	APG-AD-69
.30	1300	30°	3260	1.600	.571	2.233	2.578	68,200	NRL-O-1745
.50	1275	40°	1656	.750	.267	.623	.813	57,400	APG-AD-69
.50	1275	40°	1945	1.000	.356	.831	1.084	58,400	APG-AD-69
.50	1300	45°	1540	.497	.177	.415	.586	61,000	NRL-O-1745
.50	1275	45°	1790	.750	.267	.623	.881	57,300	APG-AD-69
.50	1300	45°	1790	.760	.271	.634	.897	57,300	NRL-O-1745
.30	1300	45°	2100	.500	.178	.698	.987	64,100	NRL-O-1745
.50	1300	46°	2085	.866	.309	.722	1.039	61,500	NRL-O-1745
.30	1355	45°	2039	.500	.178	.724	1.023	62,400	APG-AD-69
.30	1355	45°	2043	.500	.178	.724	1.023	62,500	APG-AD-69
.30	1300	46°	2630	.701	.250	.978	1.406	66,700	NRL-O-1745
.30	1300	44°	2700	.808	.289	1.127	1.567	66,000	NRL-O-1745
.30	1300	45°	2800	.808	.289	1.127	1.594	67,200	NRL-O-1745
.30	1355	50°	1837	.375	.133	.541	.841	59,100	APG-AD-69
.50	1275	50°	2038	.750	.267	.623	.969	59,300	APG-AD-69
.30	1355	50°	2346	.500	.178	.724	1.126	65,300	APG-AD-69
.50	1275	50°	2366	1.000	.356	.831	1.292	59,600	APG-AD-69
.50	1275	55°	1784	.500	.178	.415	.724	56,700	APG-AD-69
.30	1355	55°	2689	.500	.178	.724	1.262	66,700	APG-AD-69

APPENDIX C - TABLE I
(Continued)

Cal.	m/d^3	θ	V_N	e	e_1	e_1/d	$e_1/d \cos\theta$	F	Data Source
.30	1300	60°	1090	.125	.045	.173	.347	47,300	NRL-O-1745
.50	1300	60°	1890	.366	.131	.306	.611	61,700	NRL-O-1745
.30	1355	60°	2016	.250	.089	.362	.724	61,700	APG-AD-69
.50	1275	60°	2330	.500	.178	.415	.831	64,600	APG-AD-69
.50	1300	60°	2160	.503	.180	.420	.839	60,200	NRL-O-1745
.50	1300	60°	2240	.503	.180	.420	.839	62,400	NRL-O-1745
.30	1300	58.5°	2500	.359	.128	.501	.958	66,900	NRL-O-1745
.30	1355	60°	2656	.375	.133	.541	1.081	66,500	APG-AD-69
.30	1300	60°	2745	.421	.150	.587	1.174	64,600	NRL-O-1745
.50	1300	60°	2840	.760	.271	.634	1.268	64,400	NRL-O-1745
.30	1300	60°	3240	.500	.179	.698	1.395	70,000	NRL-O-1745
.30	1300	60°	3240	.503	.180	.702	1.403	69,700	NRL-O-1745
.30	1355	65°	2025	.188	.067	.272	.645	60,400	APG-AD-69
.50	1300	65°	1911	.375	.133	.311	.737	51,700	APG-AD-69
.30	1355	65°	2305	.250	.089	.362	.856	59,600	APG-AD-69
.50	1275	65°	2458	.500	.178	.415	.983	57,600	APG-AD-69
.30	1355	65°	2897	.375	.133	.541	1.280	61,300	APG-AD-69
.50	1275	70°	1780	.250	.089	.208	.607	47,700	APG-AD-69
.30	1355	70°	2352	.188	.067	.272	.780	56,700	APG-AD-69
.50	1275	70°	2238	.375	.133	.311	.911	49,000	APG-AD-69
.30	1355	70°	2468	.250	.089	.362	1.058	51,700	APG-AD-69
.50	1275	70°	2758	.500	.178	.415	1.214	52,300	APG-AD-69
.30	1355	75°	2262	.125	.044	.179	.691	50,900	APG-AD-69
.50	1275	75°	1989	.250	.089	.208	.802	40,300	APG-AD-69
.30	1355	75°	2854	.188	.067	.272	1.053	52,100	APG-AD-69
.50	1275	75°	2580	.375	.133	.311	1.203	42,700	APG-AD-69
.30	1355	75°	3033	.25	.089	.362	1.398	48,000	APG-AD-69
.30	1355	80°	2795	.125	.044	.179	1.031	41,000	APG-AD-69
.50	1275	85°	2411	.125	.044	.104	1.191	23,300	APG-AD-69
.50	1275	85°	2319	.188	.067	.156	1.792	18,300	APG-AD-69

APPENDIX C - TABLE II

Resistance to Perforation of 75ST Dural of Various Thicknesses and at Various Obliquities under Impact of Cal. .30 AP M2 and Cal. .50 AP M2 Projectiles

Cal.	m/d^3	θ	V_N	e	e_1	e_1/d	$e_1/d \cos\theta$	F	Data Source
.30	1355	0°	1571	.500	.178	.724	.724	68,000	APG-AD-218
.30	1355	0°	2035	.750	.267	1.085	1.085	71,900	APG-AD-218
.30	1355	30°	1629	.500	.178	.724	.836	61,000	APG-AD-218
.30	1355	30°	2263	.750	.267	1.085	1.253	67,200	APG-AD-218
.50	1275	40°	1804	.750	.267	.623	.813	62,500	APG-AD-218
.50	1275	45°	2116	.750	.267	.623	.881	67,700	APG-AD-218
.30	1355	45°	2131	.500	.178	.724	1.023	65,000	APG-AD-218
.30	1355	45°	2214	.500	.178	.724	1.023	67,700	APG-AD-218
.30	1355	50°	2051	.375	.133	.541	.841	66,000	APG-AD-218
.50	1275	50°	2460	.750	.267	.623	.969	71,500	APG-AD-218
.30	1355	50°	2492	.500	.178	.724	1.126	69,300	APG-AD-218
.50	1275	55°	2051	.500	.178	.415	.724	65,200	APG-AD-218
.30	1355	55°	2496	.375	.133	.541	1.081	71,700	APG-AD-218
.30	1355	55°	3030	.500	.178	.724	1.447	75,200	APG-AD-218
.50	1275	60°	2015	.375	.133	.310	.621	64,600	APG-AD-218
.50	1275	60°	2372	.500	.178	.415	.831	65,700	APG-AD-218
.30	1355	60°	2851	.375	.133	.541	1.081	71,400	APG-AD-218
.50	1275	65°	2284	.375	.133	.310	.735	61,900	APG-AD-218
.50	1275	65°	2570	.500	.178	.415	.983	60,200	APG-AD-218
.30	1355	65°	3059	.375	.133	.541	1.279	64,700	APG-AD-218
.50	1275	70°	2672	.375	.133	.310	.908	58,600	APG-AD-218
.50	1275	70°	2984	.500	.178	.415	1.215	56,500	APG-AD-218
.30	1355	70°	3084	.375	.133	.541	1.581	52,800	APG-AD-218
.50	1275	75°	2914	.375	.133	.310	1.199	48,300	APG-AD-218

APPENDIX C - TABLE III

Resistance to Perforation of 17ST Dural of Various Thicknesses and at Various Obliquities under Impact of Cal. .30 AP M2 and Cal. .50 AP M2 Projectiles

Cal.	m/d^3	θ	V_N	e	e_1	e_1/d	$e_1/d \cos\theta$	F	Data Source
.30	1300	0°	1100	.352	.126	.491	.491	56,600	NRL-O-1745
.30	1300	0°	1100	.375	.134	.523	.523	54,900	NRL-O-1745
.30	1300	0°	1520	.625	.223	.872	.872	58,700	NRL-O-1745
.30	1300	0°	2020	1.052	.376	1.468	1.468	60,200	NRL-O-1745
.30	1300	0°	2270	1.250	.447	1.743	1.743	62,000	NRL-O-1745
.30	1300	0°	2410	1.410	.504	1.967	1.967	62,000	NRL-O-1745
.30	1300	30°	1925	.705	.252	.984	1.135	60,700	NRL-O-1745
.30	1300	30°	2740	1.250	.447	1.743	2.013	64,800	NRL-O-1745

APPENDIX C - Ballistic Data Sheet No. 1

61ST Duralumin Plate No. 38071, 1/4" x 18" x 72"

Reference WA-R1588

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results	
Cal. .30 AP M2 Firings:				
45°	1	1031	PP-SB	
45°	2	1109[a,n]	PP-MB	
45°	3	1161	CP-PTP	Hit Rd. #2 - Disregard
45°	4	1173	CP-PTP	Exit hole 1/4" x 1/4"
45°	5	1119[a,n]	CP-PTP	Exit hole 1/4" x 1/4"
		[a]Army Ballistic Limit 1114 f/s		
		[n]Navy Ballistic Limit 1114 f/s		
60°	6	1583	PP-LB	
60°	7	lost	PP-LB	
60°	8	lost	PP-LB	
60°	9	1911[a,n]	CP-PTP	Exit hole 1/4" x 1/2"
60°	10	1805	PP-LB	
60°	11	1863[a,n]	PP-LB	
		[a]Army Ballistic Limit 1887 f/s		
		[n]Navy Ballistic Limit 1887 f/s		
75°	23	3009	CP-PTP	Exit hole 1/2" x 1-1/4"
75°	24	2782	CP-PTP	Exit hole 1/2" x 1-1/2"
75°	25	2702	CP-PTP	Exit hole 1/4" x 1-1/2"
75°	26	2700	CP-PTP	Exit hole 1/2" x 1-3/4"
75°	27	2572	CP-PTP	Exit hole 1/4" x 1"
75°	28	2363[a]	PP-LB	
75°	29	2392[a]	CP-FPTP	
		[a]Army Ballistic Limit 2378 f/s		
Cal. .50 AP M2 Firings:				
60°	12	1306	CP-FPTP	
60°	13	1248	CP-FPTP	
60°	14	1189	CP-FPTP	
60°	15	1175	CP-FPTP	
60°	16	1138	CP-FPTP	
60°	17	lost	PP-LB	

APPENDIX C - Ballistic Data Sheet No. 1 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 Firings (Cont'd)			
60°	18	1117[a,n]	CP-PTP Exit hole 3/8" x 1-1/2"
60°	19	1079[a,n]	PP-LB

[a]Army Ballistic Limit 1098 f/s
[n]Navy Ballistic Limit 1098 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
75°	20	1786	CP-FPTP
75°	21	1748[a]	CP-FPTP
75°	22	1737[a]	PP-LB

[a]Army Ballistic Limit 1743 f/s

APPENDIX C - Ballistic Data Sheet No. 2

61ST Duralumin Plate No. 38072, .370" x 18" x 72"
Reference WA-R1583

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings:			
30°	1	1061	CP-CIP

Army and Navy Ballistic Limits Not Determined

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
45°	2	1454	CP-PTP Exit hole 1/4" x 1/4"
45°	3	1229	PP-SB
45°	4	1298[a]	CP-CIP
45°	5	lost	Hit edge of plate - Disregard
45°	6	1250[a]	PP-SB

[a]Army Ballistic Limit 1274 f/s

APPENDIX C - Ballistic Data Sheet No. 2 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings (Cont'd):			
60°	14	2225	PP - Supported - Disregard
60°	15	2235[a,n]	CP-PTP Exit hole 1/4" x 1/2"
60°	16	2191	PP-LB
60°	17	2264[a,n]	CP-PTP Exit hole 1/4" x 1/2"
		[a]Army Ballistic Limit 2213 f/s	
		[n]Navy Ballistic Limit 2213 f/s	
75°	22	3001	PP-SB
	Army and Navy Ballistic Limits Not Determined		
Cal. .50 AP M2 Firings:			
45°	7	lost	CP-PTP Hit Rd. #3 - Disregard
45°	8	1101	CP-PTP Exit hole 9/16" x 7/16"
45°	9	986	CP-PTP Exit hole 7/16" x 9/16"
	Army and Navy Ballistic Limits Not Determined		
60°	10	1508	PP-LB
60°	11	1533[a,n]	PP-LB
60°	12	1634	CP-PTP Exit hole 3/4" x 7/16"
60°	13	1561[a,n]	CP-PTP Exit hole 3/4" x 1/2"
		[a]Army Ballistic Limit 1547 f/s	
		[n]Navy Ballistic Limit 1547 f/s	
75°	18	2670	CP-PTP Exit hole 2" x 1/2"
75°	19	2454	CP-PTP Hit Rd. #18 - Disregard
75°	20	2302[a,n]	CP-PTP Exit hole 2" x 1/4"
75°	21	2259[a,n]	PP-LB
		[a]Army Ballistic Limit 2281 f/s	
		[n]Navy Ballistic Limit 2281 f/s	

APPENDIX C - Ballistic Data Sheet No. 3

61ST Duralumin Plate No. 38073, 1/2" x 36" x 36"
Reference WA-R1584

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings:			
30°	1	1358[a,n]	PP-LB-CIP BD
30°	2	1464	CP-PTP Exit hole 1/4" x 1/4"
30°	3	1440	CP-PTP Exit hole 1/4" x 1/4"
30°	4	1400[a,n]	CP-PTP Exit hole 1/4" x 1/4"
		[a]Army Ballistic Limit 1379 f/s	
		[n]Navy Ballistic Limit 1379 f/s	
45°	5	lost	PP-SB
45°	6	1786	CP-PTP Exit hole 1/4" x 1/4"
45°	7	1747	CP-PTP Exit hole 1/4" x 1/4"
45°	8	1689[a,n]	CP-PTP Exit hole 1/4" x 1/4"
45°	9	1679[a,n]	PP-SB
		[a]Army Ballistic Limit 1684 f/s	
		[n]Navy Ballistic Limit 1684 f/s	
60°	14	2496	PP-LB
60°	15	2582	PP-LB
60°	16	2587	PP-LB
60°	17	lost	PP-LB
60°	18	lost	PP-LB
60°	19	lost	PP-LB
60°	20	2802[a,n]	PP-LB
60°	21	lost	CP-PTP Exit hole 1/4" x 1/2"
60°	22	2841[a,n]	CP-PTP Exit hole 1/4" x 1/2"
		[a]Army Ballistic Limit 2822 f/s	
		[n]Navy Ballistic Limit 2822 f/s	
Cal. .50 AP M2 Firings:			
45°	10	1187[a]	CP-CIP-FPTP
45°	11	1100	PP-LB
45°	12	1160[a]	PP-SB
45°	13	1152	PP-MB
		[a]Army Ballistic Limit 1174 f/s	

APPENDIX C - Ballistic Data Sheet No. 3 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results	
Cal. .50 AP M2 Firings (Cont'd):				
60°	23	lost	CP-PTP	Exit hole 5/8" x 1"
60°	24	2268	CP-PTP	Exit hole 1/2" x 1-3/8"
60°	25	lost	PP-NB	Backed by support - Disregard
60°	26	2264	CP-PTP	Struck Rd. #10 - Disregard
60°	27	2160[a,n]	CP-PTP	Exit hole 1-1/2" x 9/16"
60°	28	2130[a,n]	PP-LB	

[a]Army Ballistic Limit 2145 f/s
[n]Navy Ballistic Limit 2145 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
75°	29	2704	PP-LB
75°	30	2785	PP-LB
75°	31	2795	PP-LB
75°	32	2804	PP-LB
75°	33	2850	Backed by support - Disregard
75°	34	2854	PP-MB
75°	35	3021	PP-LB

Army and Navy Ballistic Limits Not Determined

APPENDIX C - Ballistic Data Sheet No. 4

61ST Duralumin Plate No. 38074, 5/8" x 36" x 36"
Reference WA-R1585

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings:			
30°	1	1545	CP-FPTP
30°	2	1350	PP-MB
30°	3	1410	PP-LB
30°	4	1500[a]	CP-FPTP
30°	5	1468[a]	PP-SB
		[a]Army Ballistic Limit 1484 f/s	
45°	14	lost	CP-PTP Exit hole 1/4" x 1/4"
45°	15	1999	PP-SB
45°	16	2024[a,n]	PP-SB
45°	17	2072[a,n]	CP-PTP Exit hole 1/4" x 1/4"
		[a]Army Ballistic Limit 2048 f/s [n]Navy Ballistic Limit 2048 f/s	
Cal. .50 AP M2 Firings:			
30°	6	1108	CP-PTP Exit hole 3/8" x 1/4"
30°	7	972	PP-Supported-Disregard
30°	8	981	CP-FPTP
30°	9	974	CP-FPTP
		Army and Navy Ballistic Limits Not Determined	
45°	10	1421	PP-MB
45°	11	1477[a,n]	CP-PTP Exit hole 7/16" x 7/16"
45°	12	lost	CP-CIP
45°	13	1449[a,n]	PP-SB
		[a]Army Ballistic Limit 1464 f/s [n]Navy Ballistic Limit 1464 f/s	
60°	18	2648	CP-PTP Exit hole 5/8" x 1-1/2"
60°	19	2525	Struck Rd. #5 - Disregard
60°	20	2427	CP-PTP Exit hole 1" x 7/16"
60°	21	2268	PP-Supported-Disregard

APPENDIX C - Ballistic Data Sheet No. 4 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 Firings (Cont'd):			
60°	22	2338[a,n]	PP-LB
60°	23	2380[a,n]	CP-PTP Exit hole 3/4" x 7/16"

[a]Army Ballistic Limit 2359 f/s
[n]Navy Ballistic Limit 2359 f/s

75°	24	2963	PP-LB

Army and Navy Ballistic Limits Not Determined

APPENDIX C - Ballistic Data Sheet No. 5

61ST Duralumin Plate No. 38075, 3/4" x 36" x 36"
Reference WA-R1586

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings:			
30°	4	1742	CP-FPTP
30°	5	lost	PP-SB
30°	6	1699[a]	CP-FPTP-CIP
30°	7	1680[a]	PP-MB-CIP

[a]Army Ballistic Limit 1690 f/s

45°	8	2230	PP-LB-CIP
45°	9	2279[a]	CP-CIP-FPTP
45°	10	2244[a]	PP-MB-CIP

[a]Army Ballistic Limit 2262 f/s

APPENDIX C - Ballistic Data Sheet No. 5 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results Results
Cal. .50 AP M2 Firings:			
30°	1	1130	CP-FPTP
30°	2	1072[a]	PP-SB-CIP
30°	3	1095[a]	CP-FPTP

[a]Army Ballistic Limit 1084 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
45°	11	1429	PP-MB
45°	12	1526	PP-SB
45°	13	1591[a,n]	PP-SB
45°	14	1624	Hit Rd. No. 5 - Disregard
45°	15	1633[a,n]	CP-PTP Exit hole 5/8" x 7/16"

[a]Army Ballistic Limit 1612 f/s
[n]Navy Ballistic Limit 1612 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
60°	16	2640	PP-LB
60°	17	lost	CP-PTP Exit hole 1-1/4" x 1/2"
60°	18	2659[a,n]	PP-LB
60°	19	2689	PP-Supported-Disregard
60°	20	2721	CP-PTP Exit hole 1-3/8" x 1/2"
60°	21	2700[a,n]	CP-PTP Exit hole 1" x 7/16"

[a]Army Ballistic Limit 2680 f/s
[n]Navy Ballistic Limit 2680 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
75°	22	2975	PP-LB

Army and Navy Ballistic Limits Not determined

Cal. .50 AP M2 Bullets Fully Yawed:

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
0°	23	2372	CP-PTP
0°	24	2283	CP-PTP
0°	25	lost	CP-PTP
0°	26	2091	CP-PTP
0°	27	1955	CP-CIP
0°	28	1895[a]	CP-CIP Pun S
0°	29	1860[a]	PP-CIP

[a]Army Ballistic Limit 1878 f/s

APPENDIX C - Ballistic Data Sheet No. 6

61ST Duralumin Plate No. 38076, 1" x 36" x 36"
Reference WA-R1587

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings:			
30°	1	2009	PP-SB-CIP
30°	2	2140[a,n]	CP-PTP Exit hole 1/4" x 1/4"
30°	3	2120[a,n]	PP-LB
		[a]Army Ballistic Limit 2130 f/s	
		[n]Navy Ballistic Limit 2130 f/s	
Cal. .30 AP M2 Firings:			
45°	15	2562	PP-SB
45°	16	2712	PP-MB
45°	17	2787[a,n]	CP-PTP Exit hole 1/4" x 1/4"
45°	18	2742[a,n]	PP-SB
		[a]Army Ballistic Limit 2765 f/s	
		[n]Navy Ballistic Limit 2765 f/s	
Cal. .50 AP M2			
30°	4	1297	PP-MB
30°	5	1360	PP-MB-CIP
30°	6	1440[a]	PP-MB
30°	7	lost	CP-Struck Rd. #6-Disregard
30°	8	1540	CP-FPTP
30°	9	1488[a]	CP-CIP
		[a]Army Ballistic Limit 1464 f/s	
45°	10	1734	PP-SB
45°	11	1821	PP-SB
45°	12	2022	CP-CIP
45°	13	1920[a,n]	PP-SB
45°	14	1969[a,n]	CP-PTP Exit hole 7/16" x 5/8"
		[a]Army Ballistic Limit 1945 f/s	
		[n]Navy Ballistic Limit 1945 f/s	

APPENDIX C - Ballistic Data Sheet No. 6 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 (Cont'd):			
60°	19	2983	PP-MB
	Army and Navy Ballistic Limits Not Determined		
Cal. .50 AP M2 Bullets Fully Yawed:			
0°	20	2067	PP-LB
0°	21	2150	PP-LB
0°	22	2247	PP-LB
0°	23	2328	PP-LB
0°	24	2461	PP-LB Slight crack
0°	25	2485	CP-PTP Incomplete Yaw-Disregard
0°	26	2515	PP-Pun S
0°	27	2595	CP-PTP No yaw-Disregard
0°	28	2564	CP-PTP No yaw-Disregard
0°	29	2572	CP-PTP Incomplete Yaw-Disregard
0°	30	2555	PP-LB Cracking
0°	31	2624	CP-PTP Incomplete Yaw-Disregard
0°	32	2620	PP-LB 2 Cracks
0°	33	2674	CP-PTP No Yaw-Disregard
0°	34	2665	PP-LB Large crack
0°	35	2700[a]	PP-LB
0°	36	2746[a]	CP-FPTP

[a]Army Ballistic Limit 2723 f/s

APPENDIX C - Ballistic Data Sheet No. 7

24ST Duralumin Plate No. 31435, 1/2" x 36" x 36"
Reference WA-R850 - See also APG-A4304 and
Figure 9 of Appendix C, this report

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings:			
30°	27	985	PP-SB
30°	28	996	PP-Yawed-Disregard
30°	29	1045	PP-Hit Rd. No. 21-Disregard
30°	30	1165	PP-NB
30°	31	1180	PP-NB
30°	32	1224	PP-SB
30°	33	1335	PP-SB
30°	34	1516	CP-PTP
30°	35	1430[a,n]	CP-PTP
30°	36	1411[a,n]	PP-SB

[a]Army Ballistic Limit 1421 f/s
[n]Navy Ballistic Limit 1421 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
45°	15	1505	PP-NB
45°	16	lost	PP-NB
45°	17	lost	PP-NB
45°	18	lost	PP-NB
45°	19	lost	PP-SB
45°	20	lost	CP-CIP
45°	21	lost	CP-PTP Exit hole 3/8" x 3/8"
45°	22	lost	CP-CIP
45°	23	lost	CP-FPTP
45°	24	2087	PP-SB
45°	25	2121[a,n]	PP-SB-CIP
45°	26	2166[a,n]	CP-PTP Exit hole 3/8" x 5/16"

[a]Army Ballistic Limit 2144 f/s
[n]Navy Ballistic Limit 2144 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
50°	52	2582	CP-CIP
50°	53	2629	CP-Supported-Disregard
50°	54	2632	CP-FPTP FS 1/2" x 1/2", BS 1/2" x 3/8"
50°	55	2502	CP-PTP Exit hole 1/2" x 3/8" FS 3/4" x 1-1/8"
50°	56	2360	PP
50°	57	2437	PP-Supported-Disregard

APPENDIX C - Ballistic Data Sheet No. 7 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings(Cont'd):			
50°	58	2442[a,n]	CP-PTP Exit hole W/BS 1/2" x 5/8" FS 11/16" x 3/4"
50°	59	2422[a,n]	PP-SB-FS 9/16" x 13/16"
		[a]Army Ballistic Limit 2432 f/s	
		[n]Navy Ballistic Limit 2432 f/s	
60°	37	2482	PP-SB
60°	38	2552	PP-SB
60°	39	2642	PP-SB
60°	40	2752	PP-SB
60°	41	2890	PP-SB
60°	42	2902	PP-MB
60°	43	2980	PP-MB
60°	44	3002	PP-MB
60°	45	3032	PP-MB
60°	46	3101	PP-LB
60°	47	3108	PP-LB
		Army and Navy Ballistic Limits not Determined	
Cal. .50 AP M2 Firings:			
45°	7	2042	CP-PTP Exit hole 1/2" x 5/8"
45°	8	1924	CP-PTP Exit hole 1/2" x 1"
45°	9	1748	CP-PTP Exit hole 7/8" x 1"
45°	10	1627	CP-PTP Exit hole 7/8" x 7/8"
45°	11	1526	CP-PTP Exit hole 1/2" x 1/2"
45°	12	1445	CP-PTP Exit hole 1/2" x 3/8"
45°	13	1370[a,n]	PP-SB
45°	14	1402[a,n]	CP-PTP Exit hole 11/16" x 1/2"
		[a]Army Ballistic Limit 1386 f/s	
		[n]Navy Ballistic Limit 1386 f/s	
50°	48	1631	PP-FS 9/16" x 2-1/4"
50°	49	1690	PP-FS 5/8" x 1-1/2"
50°	50	1745[a,n]	PP-FS 3/4" x 1-7/8"
50°	51	1791[a,n]	CP-PTP-FS 1-3/16" x 1-1/4" BS 5/8" x 7/8"
		[a]Army Ballistic Limit 1768 f/s	
		[n]Navy Ballistic Limit 1768 f/s	

APPENDIX C - Ballistic Data Sheet No. 7 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 Firings (Cont'd):			
60°	1	2525	CP-PTP-BS 2-1/4" x 15/16"
60°	2	2413	CP-PTP-FS 1/2" x 5/8", BS 7/8" x 2-1/8"
60°	3	2332	CP-PTP-FS 7/8" x 1", BS 5/8" x 5/8"
60°	4	2135	PP-MB
60°	5	2205[a,n]	PP-MB
60°	6	2255[a,n]	CP-PTP-FS 7/8" x 1-3/4", BS 5/8" x 1-1/2"

[a]Army Ballistic Limit 2230 f/s
[n]Navy Ballistic Limit 2230 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
70°	60	2456[a]	CP-FPTP
70°	61	2339	PP-MB
70°	62	2402	PP-MB
70°	63	2423[a]	PP-MB

Army Ballistic Limit 2440 f/s

APPENDIX C - Ballistic Data Sheet No. 8

24ST Duralumin Plate No. 31436, 5/8" x 36" x 36"
Reference WA R849 - See also APG-A4304 and
Figure 9 of Appendix C, this report

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings:			
30°	26	1764[a]	PP-SB-CIP
30°	27	1782[a]	CP-CIP

[a]Army Ballistic Limit 1773 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
45°	5	2594	CP-PTP Exit hole 1/4" x 3/8"
45°	6	lost	PP-SB

APPENDIX C - Ballistic Data Sheet No. 8 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings (Cont'd):			
45°	7	lost	PP-NB
45°	8	2355[a,n]	CP-PTP-BS 1/2" x 3/8"
45°	9	2323[a,n]	PP-NB
		[a]Army Ballistic Limit 2341 f/s	
		[n]Navy Ballistic Limit 2341 f/s	
50°	28	2742[a]	CP-FPTP-FS 3/4" x 1", BS 7/16" x 7/16"
50°	29	2661	PP-NB-FS 7/8" x 1/2"
50°	30	2702[a]	PP-CIP-FS 5/8" x 3/4", BS 7/16" x 1/2"
		[a]Army Ballistic Limit 2722 f/s	
Cal. .50 AP M2 Firings:			
30°	16	1174	PP-SB
30°	17	1245	CP-CIP
30°	18	1280	CP-PTP Exit hole 1/2" x 3/4"
30°	19	lost	CP-PTP Exit hole 3/8" x 1/2"
30°	20	1153	CP-CIP
30°	21	1250	CP-CIP
30°	22	1069	PP-NB
30°	23	1040[a]	PP-NB
30°	24	1132	PP-SB Hit near to Rd. #22-Disregard
30°	25	1065[a]	CP-FPTP-Pun S
		[a]Army Ballistic Limit 1053 f/s	
45°	10	2061	CP-PTP Exit hole 3/8" x 1/2"
45°	11	1865	Overlaps Rd. No. 7-Disregard
45°	12	1771	CP-CIP
45°	13	1657[a,n]	PP-SB
45°	14	1723	CP-PTP Exit hole 3/8" x 5/8"
45°	15	1695[a,n]	CP-PTP Exit hole 3/8" x 5/8"
		[a]Army Ballistic Limit 1678 f/s	
		[n]Navy Ballistic Limit 1678 f/s	
50°	31	1924[a]	PP-NB-FS 7/8" x 1-5/8"
50°	32	2100	Hit Rd. No. 2-Disregard
50°	33	1971[a]	CP-FPTP
		[a]Army Ballistic Limit 1948 f/s	

APPENDIX C - Ballistic Data Sheet No. 8 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 Firings (Cont'd):			
60°	1	2905	CP-PTP-BS 1" x 1-1/2"
60°	2	2799[a,n]	CP-PTP-BS 1-3/8" x 2-3/4", FS 1-1/8" x 3/8"
60°	3	2670	PP-MB Two 3/4" B.C.
60°	4	2770[a,n]	PP-MB 1-1/2" BC

[a]Army Ballistic Limit 2785 f/s
[n]Navy Ballistic Limit 2785 f/s

APPENDIX C - Ballistic Data Sheet No. 9

24ST Duralumin Plate No. 31437, 3/4" x 36" x 36"
Reference WA R891 - See also APG-A4304 and
Figure 9 of Appendix C this report

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings:			
30°	18	1990[a]	PP-CIP Pun S
30°	19	2055	CP-CIP-BS 3/16" x 3/8"
30°	20	2038[a]	CP-CIP-BS 1/2" x 3/8"

[a]Army Ballistic Limit 2014 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
45°	9	3008	CP-PTP-FS 5/8" x 3/4"
45°	10	2929	CP-PTP-FS 5/8" x 3/4", BS 5/16" x 1/4"
45°	11	2717	PP-SB
45°	12	2762[a,n]	CP-PTP-BS 1/2" x 7/16"
45°	13	2722[a,n]	PP-SB-FS 3/16" x 1"

[a]Army Ballistic Limit 2742 f/s
[n]Navy Ballistic Limit 2742 f/s

APPENDIX C - Ballistic Data Sheet No. 9 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings (Cont'd):			
50°	30	3091	CP-FPTP-FS 1" x 1-1/8", BS 5/16" x 1/2"
50°	31	2995	CP-FPTP-FS 1" x 5/8", BS 1/4" x 5/8"
50°	32	2887[a]	CP-FPTP-FS 1-1/8" x 7/8", BS 1/2" x 1/2"
50°	33	2838[a]	PP-SB-FS 1" x 1/2"
		[a]Army Ballistic Limit 2863 f/s	
Cal. .50 AP M2 Firings:			
30°	14	1377	CP-CIP-BS 9/16" x 5/8"
30°	15	lost	PP-Supported-Disregard
30°	16	1278[a]	PP-SB
30°	17	1287[a]	CP-FPTP Pun S
		[a]Army Ballistic Limit 1283 f/s	
45°	2	2505	CP-PTP-BS 1-7/8" x 1-1/4"
45°	3	2328	CP-PTP
45°	4	2328	CP-PTP-BS 7/8" x 1-1/8"
45°	5	2150	CP-PTP-BS 1/4" x 3/8"
45°	6	2038	CP-PTP-FS 1" x 1-5/8", BS 1/4" x 7/16"
45°	7	1924[a]	CP-FPTP-BS 1/2" x 1/4"
45°	8	1875[a]	PP-SB
		[a]Army Ballistic Limit 1900 f/s	
50°	21	2789	CP-PTP-BS 1-3/8" x 1-3/8"
50°	22	2691	CP-PTP-BS 1" x 2"
50°	23	2530	CP-PTP-BS 7/8" x 7/8"
50°	24	2432	CP-PTP-BS 1-1/4" x 3/4"
50°	25	2260	CP-PTP-BS 3/4" x 3/4"
50°	26	2150	CP-PTP-BS 3/4" x 15/16"
50°	27	2120	CP-PTP-BS 1" x 3/4"
50°	28	2040[a,n]	CP-PTP-BS 5/8" x 11/16"
50°	29	1995[a,n]	PP-NB
		[a]Army Ballistic Limit 2018 f/s [n]Navy Ballistic Limit 2018 f/s	

APPENDIX C - Ballistic Data Sheet No. 9 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 Firings (Cont'd):			
60°	1	2961	PP Crack in rear 2-1/4". Incipient BS 1-1/2" x 2-3/4"
Army and Navy Ballistic Limits Not Determined			
Cal. .50 AP M2 Bullets Completely Yawed:			
0°	34	2476	CP-PTP
0°	35	2334	CP-PTP
0°	36	2281	CP-PTP
0°	37	2257	CP-PTP
0°	38	2022	CP-PTP
0°	39	1976[a,n]	CP-PTP
0°	40	1909[a,n]	CP-PTP
0°	41	1867[a,n]	PP-MB

[a]Army Ballistic Limit 1881 f/s
[n]Navy Ballistic Limit 1881 f/s

APPENDIX C - Ballistic Data Sheet No. 10

24ST Duralumin Plate No. 31438, 1.013" x 36" x 36"
Reference WA-R892, See also APG A4304 and
Figure 9 of Appendix C, this report

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .30 AP M2 Firings:			
30°	16	2447	CP-CIP Pun 1/4" x 1/4"
30°	17	2300[a]	PP-SB
30°	18	2336[a]	CP-CIP Pun S
		[a]Army Ballistic Limit 2318 f/s	
45°	6	2702	PP-NB FS 7/8" x 1-3/8"
45°	7	2812	PP-NB FS 1" x 2"
45°	8	2923	PP-NB FS 7/8" x 3/4"
45°	9	2977[a]	PP-NB FS 1-1/2" x 1"
45°	10	3027[a]	CP-CIP Pun 1/4" x 1/4"
		[a]Army Ballistic Limit 3002 f/s	
Cal. .50 AP M2 Firings:			
30°	11	1846	CP-CIP BS 1/4" x 3/4"
30°	12	1775	CP-CIP BS 1/4" x 1/2"
30°	13	1661	CP-FPTP Pun S
30°	14	1640[a]	CP-CIP Pun S
30°	15	1590[a]	PP 1/2" BC
		[a]Army Ballistic Limit 1615 f/s	
45°	1	2373	CP-PTP BS 1/4" x 1/4" FS 1-1/4" x 1-1/4"
45°	2	2243[a,n]	CP-PTP FS 1-1/4" x 1-3/4" Slight BS
45°	3	2115	PP Struck Rd. No. 2 - Disregard
45°	4	2169	PP-MB FS 1-1/2" x 1-1/4"
45°	5	2209[a,n]	PP-NB Slight FS

[a]Army Ballistic Limit 2226 f/s
[n]Navy Ballistic Limit 2226 f/s

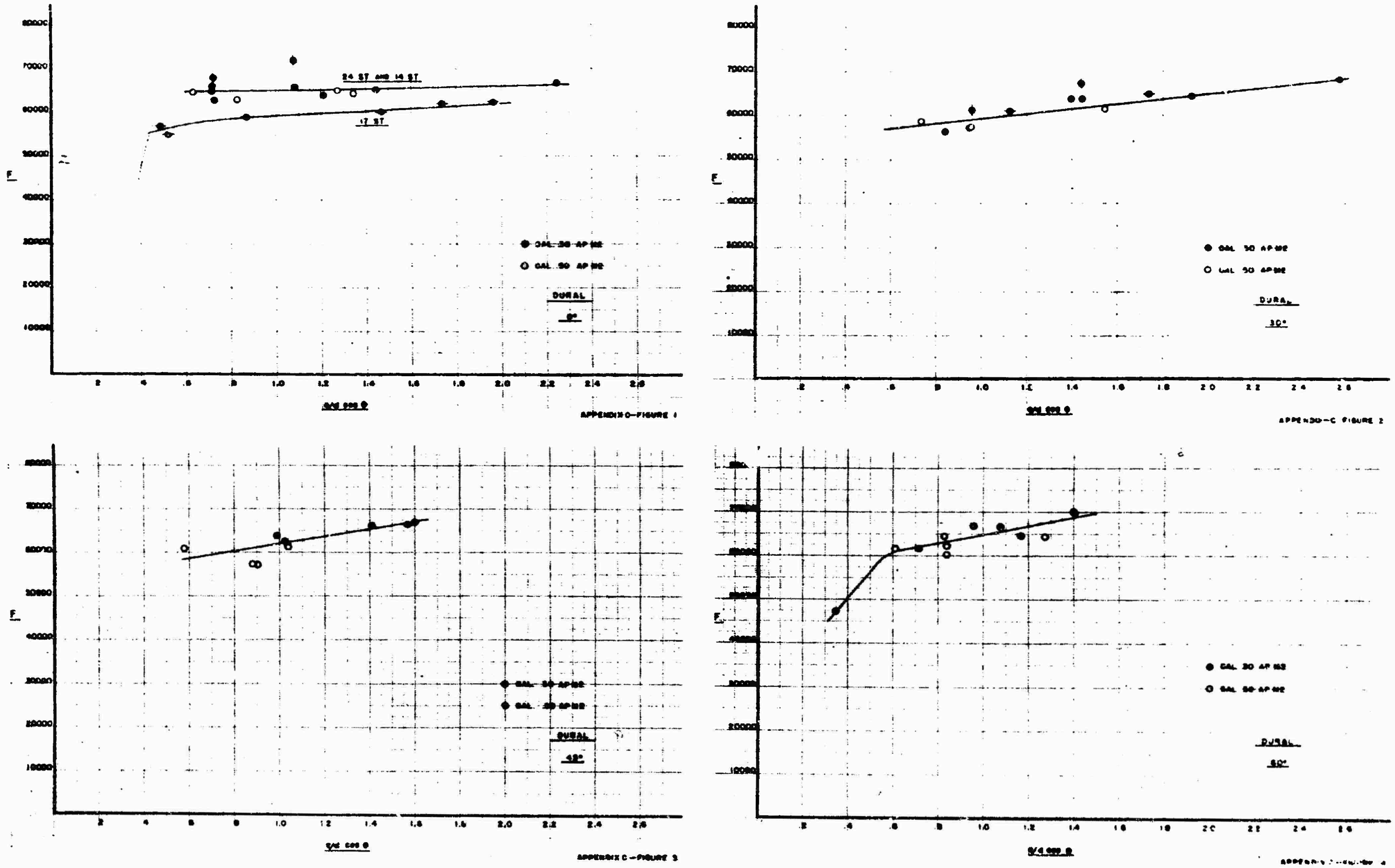
APPENDIX C - Ballistic Data Sheet No. 10 (Cont'd)

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 Firings (Cont'd):			
50°	19	2456	PP-SB FS 1-5/16" x 2-1/2"
50°	20	2750	CP-PTP FS 1-3/8" x 2-1/8", BS 1" x 1-1/16"
50°	21	2590[a]	CP-CIP FS 1-1/2" x 1-5/8", BS 3/4" x 7/8"
50°	22	2498	PP
50°	23	2541	Hit Rd. No. 22 - Disregard
50°	24	2555[a]	PP-SB FS 1-7/16" x 2"

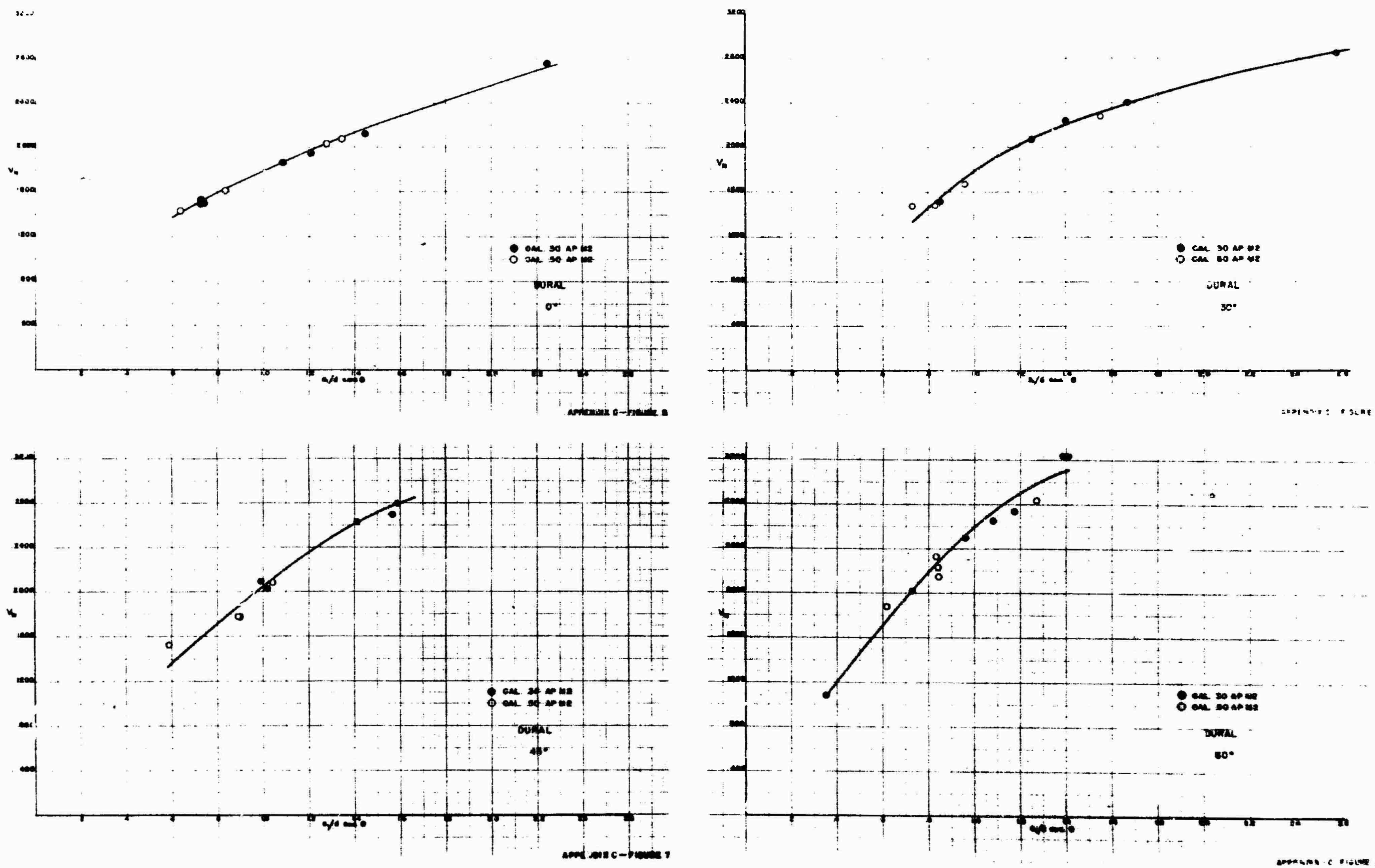
[a]Army Ballistic Limit 2588 f/s

Plate Obliquity	Plate Rd. No.	Striking Velocity	Results
Cal. .50 AP M2 Projectiles fully Yawed:			
0°	25	2184	CP-PTP
0°	26	2150[a,n]	CP-PTP
0°	27	2115[a,n]	PP-MB

[a]Army Ballistic Limit 2133 f/s
[n]Navy Ballistic Limit 2133 f/s



Appendix C - Figures 1 to 4. Duralumin (24ST). The Thompson Coefficient (F) as a Function of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel of Equivalent Weight Per Unit Surface Area (e_1), to the Projectile Core Diameter (d), with Allowance for the Greater Amount of Obliquely Installed Material Necessary to Protect a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). 0°, 30°, 45°, 60°. WTN.639-6034



Appendix C - Figures 5 to 8. Duralumin (24ST). Limit of Resistance to Perforation (V_N) as a Function of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel of Equivalent Weight Per Unit Surface Area (e_1), to the Projectile Core Diameter (d), with Allowance for the Greater Amount of Obliquely Installed Material Necessary to Protect a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). 0°, 30°, 45°, 60°.

WTN.639-6033

APPENDIX D

APPENDIX D - TABLE I

Resistance to Perforation of Dowmetal (Type FS) of Various Thicknesses and at Various Obliquities under Impact of Cal. .30 AP M2, Cal. .50 AP M2, and 20 MM AP M75 Projectiles

Cal.	m/d^3	θ	V_N	e	e_1	e_1/d	$e_1/d \cos\theta$	F	Data Source
.50	1275	0°	1230	1.110	.255	.595	.595	56,900	W.A. - R2455
.50	1275	0°	1218	1.118	.257	.600	.600	56,100	W.A. - R2415
.30	1355	0°	1307	.741	.170	.691	.691	57,900	W.A. - R2420
.50	1275	0°	1307	1.305	.300	.700	.700	55,800	W.A. - R2414
.50	1275	0°	1311	1.313	.301	.702	.702	55,900	W.A. - R2454
.30	1355	0°	1325	.766	.176	.715	.715	57,700	W.A. - R2439
.50	1275	0°	1433	1.495	.343	.800	.800	57,200	W.A. - R2413
.50	1275	0°	1415	1.499	.344	.803	.803	56,400	W.A. - R2453
.30	1355	0°	1541	.998	.229	.931	.931	58,800	W.A. - R2419
.30	1355	0°	1605	1.110	.255	1.037	1.037	58,000	W.A. - R2438
.30	1355	0°	1598	1.118	.257	1.045	1.045	57,500	W.A. - R2418
.30	1355	0°	1794	1.305	.300	1.220	1.220	59,800	W.A. - R2419
.30	1355	0°	1793	1.313	.301	1.224	1.224	59,700	W.A. - R2437
.30	1355	0°	1895	1.495	.343	1.394	1.394	59,100	W.A. - R2416
.30	1355	0°	1820	1.499	.344	1.398	1.398	56,700	W.A. - R2436
.50	1275	30°	1154	.766	.176	.411	.475	55,600	W.A. - R2405
.50	1275	30°	1273	.998	.229	.534	.617	53,900	W.A. - R2452
.30	1355	30°	1343	.635	.146	.593	.685	55,700	W.A. - R2413
.50	1275	30°	1371	1.110	.255	.595	.687	55,000	W.A. - R2411
.50	1275	30°	1392	1.118	.257	.600	.693	55,600	W.A. - R2403
.50	1275	30°	1363	1.118	.257	.600	.693	54,400	W.A. - R2451
.30	1355	30°	1352	.675	.155	.630	.727	54,300	W.A. - R2412
.30	1355	30°	1371	.741	.170	.691	.798	52,600	W.A. - R2404
.50	1275	30°	1426	1.305	.300	.700	.808	52,700	W.A. - R2450
.50	1275	30°	1395	1.313	.30.	.702	.811	51,500	W.A. - R2402
.30	1355	30°	1495	.766	.176	.715	.826	56,300	W.A. - R2410
.50	1275	30°	1511	1.499	.344	.803	.927	52,100	W.A. - R2401
.30	1355	30°	1656	.998	.229	.931	1.075	54,700	W.A. - R2446
.30	1355	30°	1776	1.110	.255	1.037	1.197	55,600	W.A. - R2409
.30	1275	30°	1832	1.118	.257	1.045	1.207	57,100	W.A. - R2408
.30	1355	30°	1989	1.305	.300	1.220	1.409	57,400	W.A. - R2445
.30	1355	30°	2084	1.313	.301	1.224	1.413	60,000	W.A. - R2407
.30	1355	30°	2124	1.499	.344	1.398	1.614	57,300	W.A. - R2406
20 MM	1295	45°	1100	1.118	.257	.328	.464	48,900	W.A. R2377
20 MM	1295	45°	1250	1.313	.301	.384	.543	51,300	W.A. - R2378
.50	1275	45°	1334	.741	.170	.397	.561	53,500	W.A. - R2392
.30	1355	45°	1364	.425	.098	.398	.563	56,300	W.A. - R2400
20 MM	1295	45°	1397	1.499	.344	.439	.621	53,600	W.A. - R2379
.30	1355	45°	1536	.635	.146	.593	.839	51,900	W.A. - R2399
.50	1275	45°	1744	1.110	.255	.595	.841	57,100	W.A. - R2391
.50	1275	45°	1763	1.118	.257	.600	.849	57,400	W.A. - R2390
.30	1355	45°	1675	.675	.155	.630	.891	54,900	W.A. - R2398

APPENDIX D - TABLE I
(Continued)

Cal.	m/d^3	θ	V_N	e	e_1	e_1/d	$e_1/d \cos\theta$	F	Data Source
.50	1275	45°	1949	1.305	.300	.700	.990	58,800	W.A. - R2389
.30	1355	45°	1704	.766	.176	.715	1.011	52,500	W.A. - R2397
.50	1275	45°	1903	1.499	.344	.803	1.136	53,600	W.A. - R2384
.30	1355	45°	2149	1.110	.255	1.037	1.467	54,900	W.A. - R2396
.30	1355	45°	2108	1.118	.257	1.045	1.478	53,700	W.A. - R2395, R2448
.30	1355	45°	2614	1.313	.301	1.224	1.731	61,500	W.A. - R2394
.30	1355	45°	2477	1.499	.344	1.398	1.977	54,500	W.A. - R2393
20 MM.	1295	60°	1200	.675	.155	.198	.396	48,500	W.A. - R2376
.50	1275	60°	1367	.425	.098	.229	.458	51,000	W.A. - R2353
20 MM.	1295	60°	1729	.998	.229	.292	.584	57,600	W.A. - R2369
20 MM.	1295	60°	1716	1.118	.257	.328	.656	53,900	W.A. - R2375
.50	1275	60°	1696	.675	.155	.362	.724	50,300	W.A. - R2354
20 MM.	1295	60°	1994	1.305	.300	.383	.766	58,000	W.A. - R2374
.50	1275	60°	1938	.741	.170	.397	.794	54,900	W.A. - R2355
.30	1355	60°	1933	.425	.098	.398	.796	56,400	W.A. - R2353
20 MM.	1295	60°	1936	1.495	.343	.438	.876	52,700	W.A. - R2350
.50	1275	60°	2377	.998	.229	.534	1.068	58,100	W.A. - R2352
.30	1355	60°	2393	.675	.155	.630	1.260	55,500	W.A. - R2354
.50	1275	60°	2702	1.313	.301	.702	1.404	57,600	W.A. - R2381
.30	1355	60°	2632	.766	.176	.715	1.430	57,300	W.A. - R2383
.50	1275	60°	2810	1.495	.343	.800	1.600	56,100	W.A. - R2351
.30	1355	60°	2913	1.110	.255	1.037	2.074	52,600	W.A. - R2382
.50	1275	60°	2177	1.118	.257	.600	1.200	50,200	W.A. - R2380
20 MM.	1295	75°	1298	.425	.098	.125	.483	34,200	W.A. - R2360
20 MM.	1295	75°	1748	.741	.170	.217	.838	35,000	W.A. - R2356
.50	1275	75°	1990	.425	.098	.229	.885	38,400	W.A. - R2348
20 MM.	1295	75°	2389	.998	.229	.292	1.128	41,200	W.A. - R2368
.50	1275	75°	2541	.635	.146	.341	1.318	40,200	W.A. - R2346
.50	1275	75°	2441	.675	.155	.362	1.399	37,500	W.A. - R2347
.30	1355	75°	2787	.425	.098	.398	1.538	42,100	W.A. - R2348
.50	1275	75°	2643	.766	.176	.411	1.588	38,100	W.A. - R2358

APPENDIX D - TABLE II

Resistance to Perforation of Dowmetal (Type J-1h) Various Thicknesses and at Various Obliquities under Impact of Cal. .30 AP M 2 and Cal. .50 AP M2 Projectiles

Cal.	m/d^3	θ	V_L	e	e_1	e_1/d	$e_1/d \cos \theta$	Data Source
.50	1275	30°	1082	.750	.172	.402	.464	W.A. 470.5/5482
.30	1355	30°	1041	.498	.114	.465	.537	W.A. 470.5/5184
.30	1355	30°	1088	.504	.116	.470	.543	W.A. 470.5/5482
.30	1355	30°	1250	.563	.129	.525	.743	W.A. 470.5/5482
.50	1275	30°	1222	1.000	.230	.536	.619	W.A. 470.5/5184
.30	1355	30°	1251	.607	.139	.567	.654	W.A. 470.5/5184
.30	1355	30°	1436	.750	.172	.700	.808	W.A. 470.5/5184
.30	1355	30°	1627	1.000	.230	.933	1.078	W.A. 470.5/5184
.50	1275	45°	1166	.607	.139	.325	.460	W.A. 470.5/5184
.50	1275	45°	1285	.750	.172	.402	.568	W.A. 470.5/5184
.30	1355	45°	1348	.498	.114	.465	.657	W.A. 470.5/5184
.30	1355	45°	1408	.504	.116	.470	.665	W.A. 470.5/5482
.30	1355	45°	1524	.563	.129	.525	.743	W.A. 470.5/5482
.50	1275	45°	1510	1.000	.230	.536	.758	W.A. 470.5/5184
.30	1355	45°	1495	.607	.139	.567	.801	W.A. 470.5/5184
.30	1355	45°	1699	.750	.172	.700	.990	W.A. 470.5/5184
.30	1355	45°	2043	1.000	.230	.933	1.320	W.A. 470.5/5184
.50	1275	50°	1751	.625	.143	.335	.521	APG-A4074
.50	1275	60°	1046	.376	.086	.197	.393	W.A. 470.5/5184
.30	1355	60°	1126	.249	.057	.232	.465	W.A. 470.5/5184
.50	1275	60°	1299	.498	.114	.267	.534	W.A. 470.5/5184
.50	1275	60°	1375	.504	.116	.270	.540	W.A. 470.5/5482
.50	1275	60°	1396	.504	.116	.270	.540	W.A. 470.5/5482
.50	1275	60°	1650	.563	.129	.302	.603	W.A. 470.5/5482
.50	1275	60°	1661	.563	.129	.302	.603	W.A. 470.5/5482
.50	1275	60°	1536	.607	.139	.325	.650	W.A. 470.5/5184
.50	1275	60°	2446	.625	.143	.335	.670	APG-A4074
.30	1355	60°	1706	.376	.086	.351	.702	W.A. 470.5/5184
.50	1275	60°	1825	.750	.172	.402	.804	W.A. 470.5/5184
.30	1355	60°	2029	.498	.114	.465	.930	W.A. 470.5/5184
.30	1355	60°	2034	.504	.116	.470	.941	W.A. 470.5/5482
.30	1355	60°	2158	.563	.129	.525	1.051	W.A. 470.5/5482
.50	1275	60°	2266	1.000	.230	.536	1.072	W.A. 470.5/5184
.30	1355	60°	2210	.607	.139	.567	1.133	W.A. 470.5/5184
.30	1355	60°	2417	.750	.172	.700	1.400	W.A. 470.5/5184
.30	1355	60°	2787	1.000	.230	.933	1.867	W.A. 470.5/5184
.50	1275	70°	1121	.325	.075	.174	.509	APG-A4074
.50	1275	70°	1307	.375	.086	.201	.587	APG-A4074
.50	1275	75°	1193	.249	.057	.133	.514	W.A. 470.5/5184
.50	1275	75°	982	.250	.057	.134	.517	APG-A4074
.50	1275	75°	1272	.325	.075	.174	.673	APG-A4074
.50	1275	75°	1451	.375	.086	.201	.776	W.A. 470.5/5184

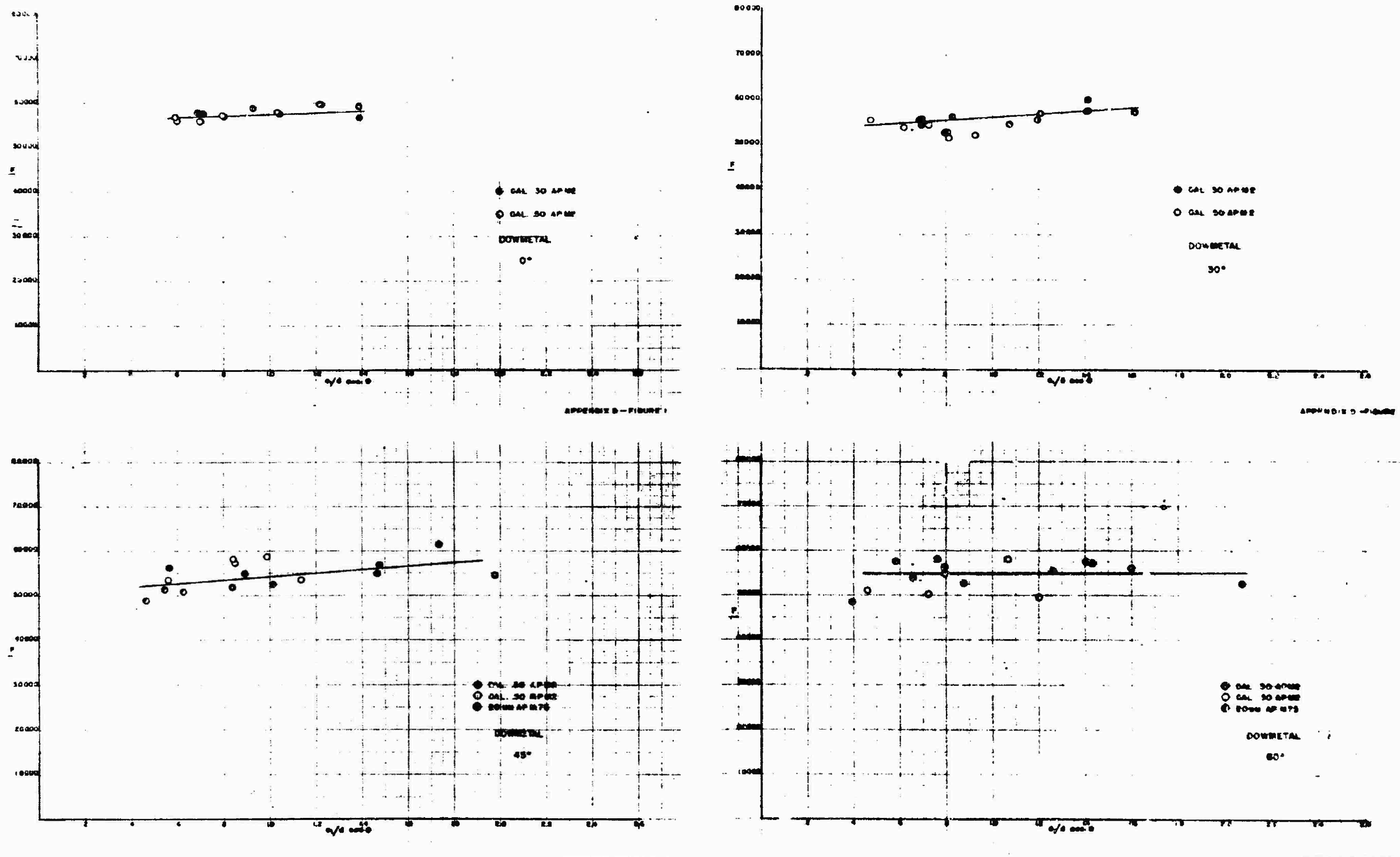
APPENDIX D - TABLE II
(Continued)

Cal.	m/d^3	θ	V_L	e	e_1	e_1/d	$e_1/d \cos \theta$	Data Source
.50	1275	75°	1576	.375	.086	.201	.776	APG-A4074
.30	1355	75°	1868	.249	.057	.232	.898	W.A. 470.5/5184
.50	1275	75°	1915	.498	.114	.267	1.031	W.A. 470.5/5184
.50	1275	75°	1781	.504	.116	.270	1.043	W.A. 470.5/5482
.50	1275	75°	2362	.563	.129	.302	1.166	W.A. 470.5/5482
.50	1275	75°	2381	.607	.139	.325	1.257	W.A. 470.5/5184
.30	1355	75°	2631	.376	.086	.351	1.356	W.A. 470.5/5184
.50	1275	75°	2775	.750	.172	.402	1.553	W.A. 470.5/5184
.30	1355	75°	2811	.504	.116	.470	1.818	W.A. 470.5/5482
.30	1355	80°	1251	.125	.029	.117	.672	APG-A4074
.50	1275	80°	1146	.250	.057	.134	.772	APG-A4074
.30	1355	80°	1664	.187	.042	.175	1.005	APG-A4074

APPENDIX D - TABLE III

Resistance to Perforation of Dowmetal (Type J, as Hot Rolled) Various Thicknesses and at Various Obliquities under Impact of Cal. .30 AP M2 and Cal. .50 AP M2 Projectiles

Cal.	m/d^3	θ	V_L	e	e_1	e_1/d	$e_1/d \cos\theta$	F	Data Source
.50	1275	30°	1222	1.000	.230	.536	.619	51,600	W.A. 470.5/5184
.30	1355	30°	1436	.750	.172	.700	.808	54,700	W.A. 470.5/5184
.50	1275	45°	1166	.607	.139	.325	.460	51,600	W.A. 470.5/5184
.50	1275	45°	1285	.750	.172	.402	.568	51,200	W.A. 470.5/5184
.50	1275	45°	1510	1.000	.230	.536	.758	52,100	W.A. 470.5/5184
.30	1355	45°	2043	1.000	.230	.933	1.320	55,000	W.A. 470.5/5184
.50	1275	60°	1078	.376	.086	.197	.393	43,400	W.A. 470.5/5184
.30	1355	60°	1167	.249	.057	.232	.465	44,600	W.A. 470.5/5184
.50	1275	60°	1299	.498	.114	.267	.534	44,900	W.A. 470.5/5184
.50	1275	60°	1536	.607	.139	.325	.650	48,100	W.A. 470.5/5184
.30	1355	60°	2029	.498	.114	.465	.930	54,800	W.A. 470.5/5184
.50	1275	60°	2266	1.000	.230	.536	1.072	55,300	W.A. 470.5/5184
.30	1355	60°	2210	.607	.139	.567	1.133	54,000	W.A. 470.5/5184
.30	1355	60°	2417	.750	.172	.700	1.400	53,200	W.A. 470.5/5184
.30	1355	60°	2787	1.000	.230	.933	1.866	53,100	W.A. 470.5/5184
.50	1275	75°	1451	.376	.086	.197	.760	30,200	W.A. 470.5/5184
.50	1275	75°	1915	.498	.114	.267	1.031	34,300	W.A. 470.5/5184
.30	1355	75°	2631	.376	.086	.351	1.356	42,300	W.A. 470.5/5184
.50	1275	75°	2775	.750	.172	.402	1.553	40,500	W.A. 470.5/5184



Appendix D - Figures 1 to 4. Dowmetal (Type FS). The Thompson Coefficient (F) as a Function of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel of Equivalent Weight Per Unit Surface Area (e_1), to the Projectile Core Diameter (d), with Allowance for the Greater Amount of Obliquely Installed Material Necessary to Protect a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). 0°, 30°, 45°, 60°.

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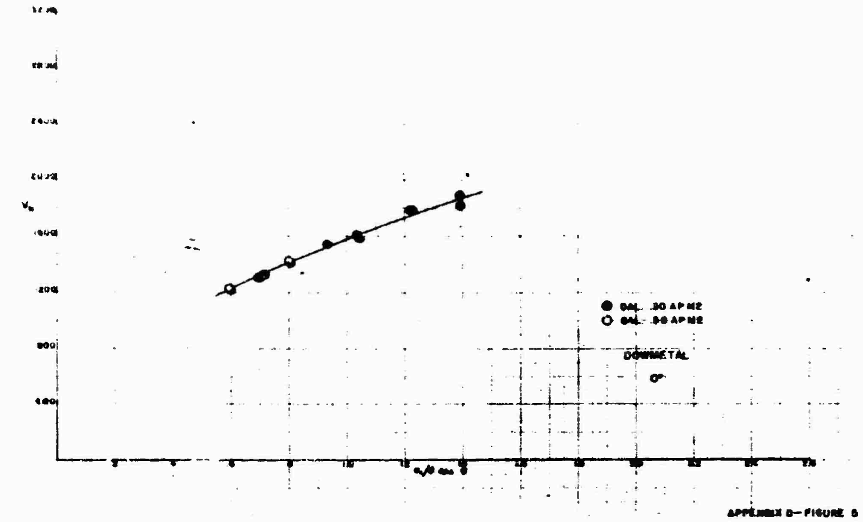

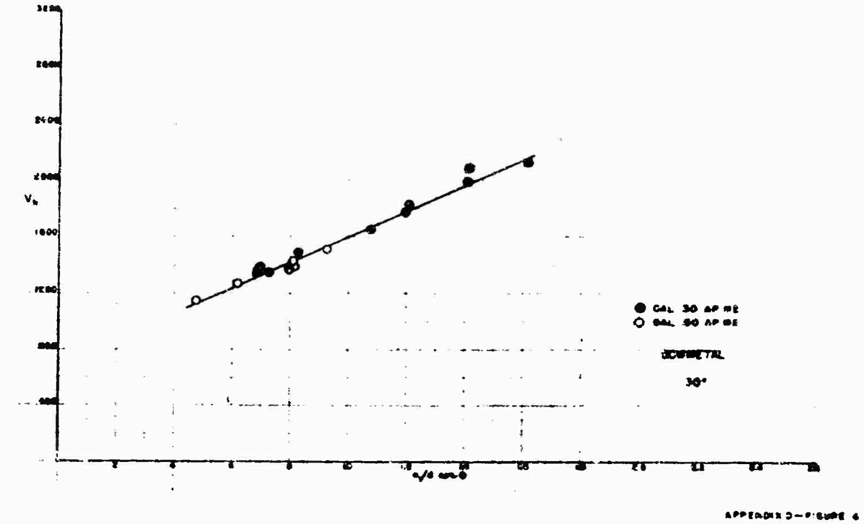

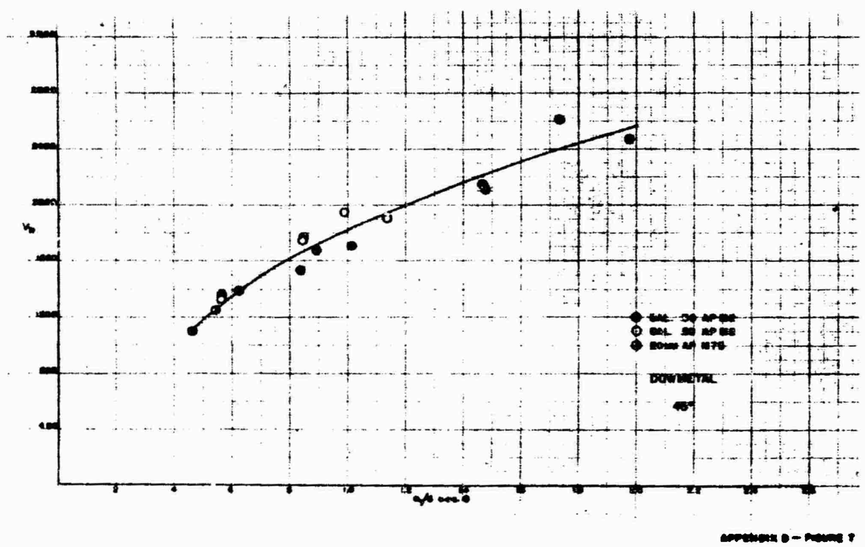

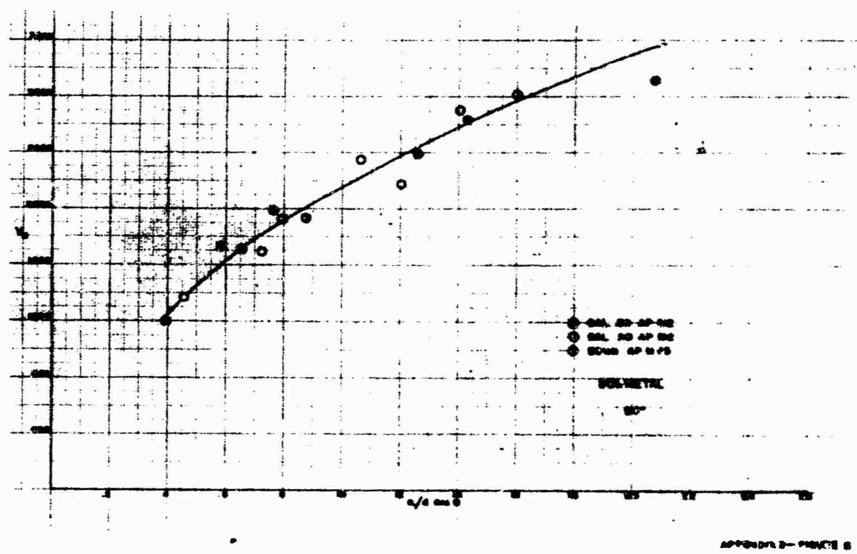

Appendix - Figures 5 to 8. Dowmetal (Type FS). Limit of Resistance to Perforation (V_N) as a Function of the Ratio of Plate Thickness (e), Corrected to the Thickness of Steel of Equivalent Weight Per Unit Surface Area (e_1), to the Projectile Core Diameter (d), with Allowance for the Greater Amount of Obliquely Installed Material Necessary to Protect a Unit Area Normal to the Line of Fire ($e_1/d \cos \theta$). 0°, 30°, 45°, 60°.

WTN.639-6031

APPENDIX E - CORRESPONDENCE

COPY

WAR DEPARTMENT
AIR CORPS
MATERIEL DIVISION
Office of the Ordnance Officer — CMcI:faw:95

Wright Field, Dayton, Ohio

WF 00 470.55

January 13, 1943

Subject: Ballistic Limit Curves for Armor Plate and Dural.

To: Commanding Officer
Watertown Arsenal
Watertown, Massachusetts

Attn: Ferrous Metallurgical Advisory Board,
Colonel H. H. Zornig.

1. Attached are curves giving the ballistic limit of various thicknesses of 24ST Dural as taken from Aberdeen Proving Ground Report AD-69.

2. It is to be noted that the armor plate is specification requirements under ANOS-1 and, therefore, the direct relationship between dural and specification limits under ANOS-1 is not exact.

3. If these curves meet with your approval, it is requested that copies be furnished to members of the Aircraft Armor Fabricators' Group of the Subcommittee on Welding of Armor Plate.

(S/T) C. H. MORGAN,
Colonel, Ord. Dept.,
Ordnance Officer.

1 Incl.
Set of Photostats.

COPY

WF 00 470.55
W.A. 470.5/5876 1st Ind. NAM/SULLIVAN/amv

Watertown Arsenal, Watertown, Massachusetts, January 25, 1943.

To: Chief of Ordnance, U.S.A., Pentagon Building, Washington, D.C.
Attn: SPOTB

1. In reference to the data accompanying the basic letter, it is felt that a more comprehensive report would better fulfill requirements of the Aircraft Armor Fabricators Group of the Subcommittee on Welding of Armor.

2. It is suggested that this Arsenal prepare a report covering several tests of dural and other light alloys in which an analysis of the results of such tests would be made. Such a report would present a more complete picture of the situation and afford a basis for determination of the relative value of the different materials as armor in aircraft.

3. Permission to prepare and distribute such a report is sought of his office.

For the Commanding Officer:

H. H. ZORNIG
Colonel, Ord. Dept.
Director of Laboratory

1 Incl.
Set of Photostats

COPY

O.O. 470/4330 (r)
Attn: SPOTB
W.A. 470.5/5876

2nd Ind.

Webster/fr
2300

War Department, Ordnance Office, Washington, D.C. February 9, 1943.

To: Commanding Officer, Watertown Arsenal, Watertown, Mass.

1. It is authorized that a substantially informative report be compiled by the laboratory to give data usable in design particularly for aircraft use. It is suggested that known data on duralumin (especially 24ST with 14ST) be collated in such graphical presentation to afford easy use for the designing engineer. Furthermore, distribution of this report should be made to fabricators through Wright Field for aircraft and through Tank Automotive Center for combat vehicles.

2. In compiling this report, the Aberdeen Proving Ground tests noted in basic letter, the Watertown Arsenal data and the reports from the Naval Research Laboratory should be analyzed. To completely collate and combine these data, the ballistic limits should be based on the Navy Criterion, thus giving the upper immunity limit directly. Also, if plots are based on the ratio of actual thickness of plate to diameter of projectile ($e/d \cos \theta$), various projectiles and thicknesses of plate can be directly compared. For the thickness of light alloys instead of e, the use of e_1, or the equivalent thickness of steel will afford also direct comparison with steel armor. These comparisons with face-hardened and hard homogeneous should also be shown.

3. The following pertinent reports from the Naval Research Laboratory are cited:

> Attached copy of Plate I, Second Partial Report on Light Armor; Composite uses of duralumin, Fourth Partial Report on Light Armor; Use of shielding structures, Fifth Partial Report on Light Armor; Use of duralumin, Seventh Partial Report on Light Armor; Comparison of duralumin with face-hardened armor plate, Eighth Partial Report on Light Armor; and Paragraph 35, page 11, Ninth Partial Report on Light Armor.

4. If copies of any of these reports are not available, this office will furnish them upon request. Please expedite and return to this office.

By Order of the Chief of Ordnance:

(S/T) G. Elkins Knable,
Col., Ord. Dept.,
Assistant.

Incls.:
1 - Set of Photostats (12 sheets)
w/Plate 1 & Chart.

APPENDIX F - EXPLANATION OF ABBREVIATIONS

Key to Sources of Data Indicated in Appendix A - Table I; Appendix B - Table I; Appendix C - Tables I, II, III; Appendix D - Table I;

Symbol	Reference
APG-A7196	Development Test of Armor Plate. Firing Record No. A7196. The Proving Center, Aberdeen Proving Ground, Maryland, 25 February 1943.
APG-A7472	Armor Test Report No. A-7472. The Proving Center, Aberdeen Proving Ground, Maryland, 15, 16, July 1943.
APG-A9485	Armor Test Report No. A-9485. The Proving Center, Aberdeen Proving Ground, Maryland, 30 September 1943.
APG-A9486	Armor Test Report No. A-9486. The Proving Center, Aberdeen Proving Ground, Maryland 30 September 1943.
APG-AD-52	Development of Chemical Analyses for Face-Hardened Aircraft Armor. Armor Test Report No. AD-52. The Proving Center, Aberdeen Proving Ground, Maryland, 29 September 1942.
APG-AD-69	Development of 24ST Duralumin for Aircraft Armor. Armor Test Report No. AD-69. The Proving Center, Aberdeen Proving Ground, Maryland, 11-18 November 1942.
APG-AD-147	Development of Analyses for Face-Hardened Aircraft Armor. Armor Test Report No. AD-147. The Proving Center, Aberdeen Proving Ground, Maryland, 18 December 1942.
APG-AD-148	Development of Analyses for Face-Hardened Aircraft Armor. Armor Test Report No. AD-148. The Proving Center, Aberdeen Proving Ground, Maryland, 15, 16, 22, December 1942.
APG-AD-218	Development Test of A-75 S-T Aluminum Alloy Aircraft Armor. Armor Test Report No. AD-218. The Proving Center, Aberdeen Proving Ground, Maryland, 30 January 1943.
NPG-18-43	Ballistic Performance of 24ST Aluminum Alloy Protection Against Aircraft Projectiles. U.S. Naval Proving Ground, Dahlgren, Virginia. Report No. 18-43, 10 August 1943.

Symbol	Reference
NRL-0-1745	Eight Partial Reports on Light Armor. The Performance of Bullet Proof Steel and Aluminum Alloys Against Small Caliber A.P. Bullets and the Effect Upon Plate Performance of Bullet Fracture and Obliquity. G.R. Irwin and C.H. Kingsbury, Naval Research Laboratory, Anacostia Station, Washington, D.C. 22 May 1941. (Confidential)
W.A. 710/456	Rolled Armor - Ballistic Properties of Rolled Face-Hardened and Rolled Homogeneous Armor of Various Hardnesses at Normal Incidence and at Various Obliquities. J. Sullivan, Watertown Arsenal Laboratory, Experimental Report No. 710/456, 28 September 1942.
W.A. 710/493	Aircraft Armor - An Analysis of Firings of Rolled Homogeneous Armor Submitted under Specification ANOS-1. J. Sullivan, Watertown Arsenal Laboratory, Experimental Report No. WAL 710/493, 15 October 1943.
W.A. R-2182	Watertown Arsenal Firing Range Record No. R-2182. See Appendix B - Ballistic data sheet No. 5.
W.A. R-2183	Watertown Arsenal Firing Range Record No. R-2183. See Appendix B - Ballistic data sheet No. 6.
W.A. R-2184	Watertown Arsenal Firing Range Record No. R-2184. See Appendix B - Ballistic data sheet No. 4.
W.A. R-2185	Watertown Arsenal Firing Range Record No. R-2185. Appendix B - Ballistic data sheet No. 3.
W.A. R-2186	Watertown Arsenal Firing Range Record No. R-2186. See Appendix B - Ballistic data sheet No. 2.
W.A. R-2187	Watertown Arsenal Firing Range Record No. R-2187. See Appendix B - Ballistic data sheet No. 1.
W.A. R-2346-48, 50-56, 60, 68, 69, 74-84, 89. W.A. R-2416, 18-20, 36-39, 45, 46, 48 50-55	Watertown Arsenal Firing Range Records Nos. 2346 2455. See also Watertown Arsenal Laboratory Experimental Report No. WAL 710/265. Aircraft Armor - Ballistic Characteristics of a Magnesium Alloy Dowmetal (Type FS), J. Sullivan 22 October 1943.

Key to Abbreviations Used in Ballistic Data Sheets

BC	-	Back crack.
BS	-	Back spall.
CIP	-	Core of projectile retained in plate.
CP	-	Complete penetration.
FPTP	-	Projectile failed to pass through plate.
FS	-	Face spall.
LB	-	Large bulge on back of impact.
MB	-	Medium bulge on back of impact.
PP	-	Partial penetration.
PTP	-	Projectile passed through plate.
SB	-	Small bulge on back of impact.

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Security Classification

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13. ABSTRACT

The object of the original study was to collate, integrate and analyze data concerning the ballistic characteristics of steel (face-hardened, rolled homogeneous) and lighter alloys (duralumin, Dowmetal) and present the results in a form suitable for use by the designer and fabricator of aircraft armor.

This "classical" study of aircraft armor was distributed as a W. A. L. report, WAL 710/506, to a specific list of recipients over 25 years ago and has been out of print for several years. Until recently it has also been under security restrictions. Accordingly, its contents are generally unknown to most of today's researchers in armor materials.

Although this study was written during a much less sophisticated era of materials technology and was limited to a review of materials reasonably available at that time whose relative performance was judged under the restrictive ground rule of retention of structural integrity under multiple projectile hits, it is believed that the report may contain information and philosophy "new" to today's researcher whose horizons fortunately are not limited by such restrictions. (Author)

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Armor Aircraft armor Ballistics Steel Aluminum copper alloys Magnesium						